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Special Technical Report 37

ANALYSIS OF MEDIUM- AND HIGH-FREQUENCY ATMOSPHERIC RADIO NOISE IN THAILAND

By: RANGSIT CHINDAHPORN E. LEROY YOUNKER

Prepared for:

U.S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY 07703

CONTRACT DA 36-039 AMC-00040(E)
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SRI Project 4240

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ABSTRACT

Measurements of atmospheric radio noise have been made in Thailand since early 1966 using equipment similar to the ARN-2 noise-measuring sets employed in the worldwide noise-measuring network coordinated by the Environmental Science Services Administration (ESSA) of the U.S. Department of Commerce. Emphasis is placed in this report on noise power measurements at 0.53, 2.3, 5.0, and 10.0 MHz. The analysis of data from almost two years of measurements shows that the variation in the magnitude of noise power from day to night in Thailand is typically 25 dB and indicates that a seasonal variation of about 10 dB is superimposed upon the diurnal effect. The day-to-day variation of noise power at any given hour is considerable, the range between upper and lower decile values of daily measurements made during any month being typically 20 dB. A comparison of measured values of noise power with CCIR predictions for the measuring site showed that the actual noise is substantially greater than that predicted. In general, the largest discrepancies between measurement and prediction occur between 0800 and 1600 hours and are of the order of 14 dB. At other times of the day and night the discrepancy is approximately 7 dB. A study of measured and predicted data for Singapore also shows that the discrepancy between measurement and prediction is larger during the daytime, but the magnitude of the effect is somewhat smaller. An investigation of the effects of local electrical storms--as indicated by lightning-flash counters--shows that the hourly ~~hour by~~ average noise power tends to increase as the number of flash counts increases, and this effect is greater at the lower frequencies.

PREFACE

The work described in this report was performed with the support, and using the facilities, of the Military Research and Development Center (MRDC) in Bangkok, Thailand. The MRDC is a joint Thai-U.S. organization established to conduct research and development work in the tropical environment. The overall direction of the U.S. portion of the MRDC has been assigned to the Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense, which in 1962 asked the U.S. Army Electronics Command (USAECOM) and the Stanford Research Institute (SRI) to establish an electronics laboratory in Thailand to facilitate the study of radio communications in the tropics and related work. The MRDC-Electronics Laboratory (MRDC-EL) began operation in 1963 [under Contract DA 36-039 AMC-00040(E)], and since that time ARPA has actively monitored and directed the efforts of USAECOM and SRI. In Bangkok, this function is carried out by the ARPA Research and Development Field Unit (RDFU-T). The cooperation of the Thai Ministry of Defense, Ministry of the Interior and the Thailand and CONUS representatives of ARPA and USAECOM made possible the work presented in this report.

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ACKNOWLEDGMENTS

The authors gratefully acknowledge the excellent cooperation of the officers in various agencies of the Thai government. They especially appreciate the help of the Ministry of Interior's officers, and their permission to use the land under their responsibility and control at Laem Chabang.

The authors wish to express their appreciation to Mr. W. Q. Crichlow of the U.S. Environmental Science Services Administration, Boulder, Colorado, and his staff for many helpful comments, and for providing the scaled data from Singapore and New Delhi.

The authors are also pleased to thank Professor S. A. Prentice of University of Queensland, Brisbane, Australia, for the loan of a transistorized ERA lightning flash counter.

Finally, the authors wish to thank their colleagues at SRI who have made significant contributions to the noise-measurement program, particularly Dr. E. T. Pierce, Mr. R. L. Brown, and Mr. G. H. Hagn. Thanks also are due Lt. Chaikamol Lumjiak of the Royal Thai Air Force, Mr. Pinyo Charusingha, and Mr. Noey Ponpai of SRI Bangkok for participating and assisting in the operation and maintenance of the equipment, and Mr. Polsuk Buasree for supervising the data reduction.

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I INTRODUCTION

For radio communication systems working in the high-frequency band (3-30 MHz) atmospheric radio noise is (in the absence of man-made interference) the limiting factor that usually determines whether a received signal is usable for the transmission of information. Since atmospheric radio noise is especially severe in the tropics, the MRDC-EL in Bangkok has included the measurement of radio noise in its program since the official opening of the laboratory in late 1963. Early measurements* were made with an Empire Devices noise and field-intensity meter in the MF and HF bands, with a six-channel noise receiver and recorder in the VLF and LF bands, and supplementary data were collected with a lightning-flash detector. While these measurements provided useful information, they emphasized the need for collecting data over a long period of time and for using equipments wherever possible that would provide data comparable with data collected elsewhere. In particular, the importance of comparing measured noise with "predictions"† for Thailand scaled from noise maps prepared by the International Radio Consulative Committee (CCIR) of the International Telecommunication Union[1§] became apparent.

In order to meet the above objectives, several comprehensive noise-measuring equipments were designed and constructed in 1965 and put into operation in 1966. One new equipment was a noise-measuring set whose data output was compatible with the standard ARN-2 noise-measuring set[2] used by ESSA in its worldwide network of noise-measuring stations. This equipment

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* Memorandum for SRI Project 4240 Task II, "Summary of MRDC Electronics Laboratory RF Noise Measurements through 1964," by R. E. Leo and Rangsit Chindahporn, January 1965.

† The term "predictions" is used for convenience, since the CCIR Report No. 322 actually contains an orderly tabulation of past observations and no attempt at prediction based on meteorological and ionospheric forecasts is made. Hence, the CCIR maps labeled "expected values of atmospheric radio noise" are predictions only to the extent that the future repeats the past.

§ References are listed at the end of the report.

was called the ARN-3-type atmospheric noise-measuring equipment[3] and is referred to in the remainder of this report as the ARN-3. It retains the essential operating specifications of the ARN-2 but differs somewhat in physical construction and includes some extra design features to permit using the equipment in special noise-measuring experiments.

The ARN-3 was designed to measure two noise parameters, F_a and V_d, at each of four frequencies in the HF and MF bands, and, by making use of time sharing, it was also designed to do so at four other frequencies in the LF and VLF bands. The effective antenna noise factor F_a represents mean noise power in dB relative to the thermal noise power available from a passive resistance of 288^0 Kelvin. The voltage deviation V_d is the ratio (in dB) of the mean-squared noise voltage $(V_{rms})^2$ to the square of the average voltage of the noise envelope, where both voltages are measured after linear detection [i.e., $V_d = 20 \log_{10} (V_{rms}/V_{avg})$]. Of course, $(V_{rms})^2$ is proportional to the mean noise power.

New lightning-flash counters[4,5] were also designed and constructed in order to give a more complete coverage of lightning activity as a function of threshold levels and frequency bands of the lightning-flash-detecting equipment. These equipments were used in a study of the effects of local storms on effective antenna noise factor.

The ARN-3 was installed at a field site having little man-made noise early in 1966, and it has operated continuously until March 1968. Valid data on 0.53, 2.3, 5.0, and 10.0 MHz for the noise power and noise-voltage deviation collected since March 1966 have been published in a series of geophysical data reports.[6-13] The analysis of these data and the comparison of measured values with predictions of noise from the CCIR world-wide maps form the bulk of this technical report.

II DESCRIPTION OF INSTRUMENTATION AND PROCEDURES

A. Test-Site Installation

Early noise measurements at Bangkok showed conclusively that the high-level of man-made noise made the measurement of atmospheric radio noise impossible in the city. The following requirements were set down for a site that would be suitable as an atmospheric noise-measuring station:

(1) It must be at least 1 km from all main roads.

(2) It must be at least 3 km from electrical power distribution lines at voltages exceeding 5 kilovolts.

(3) It should have a low horizon (4^0 or less) in all directions in order to allow comparison of data taken on the standard ARN-2 equipment antenna with data from the CCIR worldwide noise-measuring network.

(4) The probability that the site would remain electrically quiet in the foreseeable future should be high.

(5) It should be located not more than 2 hours by automobile from MRDC-EL in Bangkok.

(6) It must be accessible from a main road in all seasons.

(7) It must have a usable area of approximately 300 by 300 meters.

(8) The surrounding area must be free of structures and all man-made activity except normal agricultural operations.

As a result of a survey in late 1964, a site near the village of Laem Chabang (13.05^0N, 100.9^0E) about 90 km southeast of Bangkok was selected (see Fig. 1). This site is on property of the Ministry of the Interior and more than meets all the above requirements. For example, the site is over 5 km from any highway or any electric power lines, and no one in the area uses equipment that would produce ignition noise.

The overall layout of the Laem Chabang low-noise site installation is shown in Fig. 2. The white building in the center of the photograph is the equipment van with air-conditioning. Power is supplied to the equipment through buried cables from diesel generators located in the

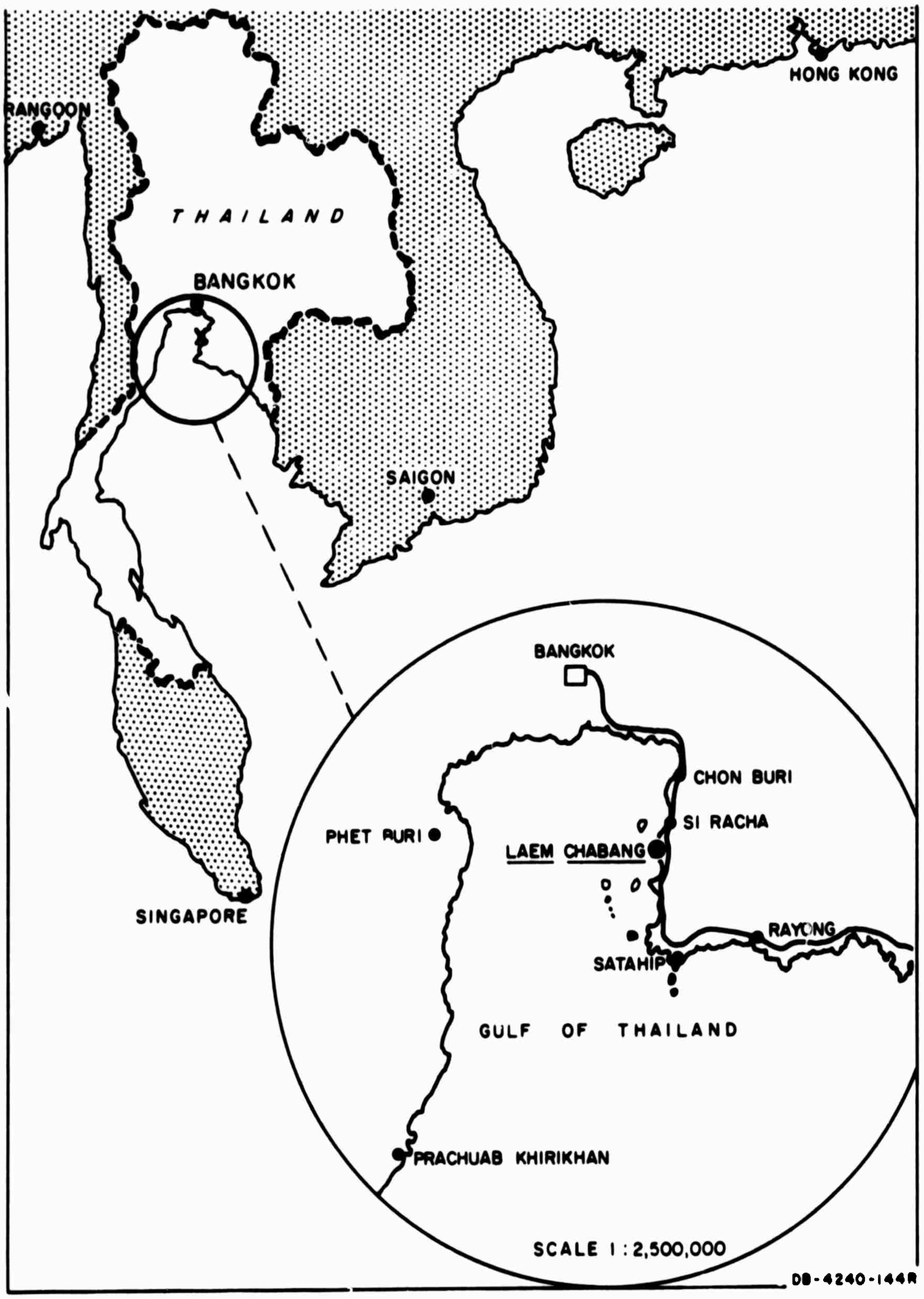


FIG. 1 MAP SHOWING LAEM CHABANG

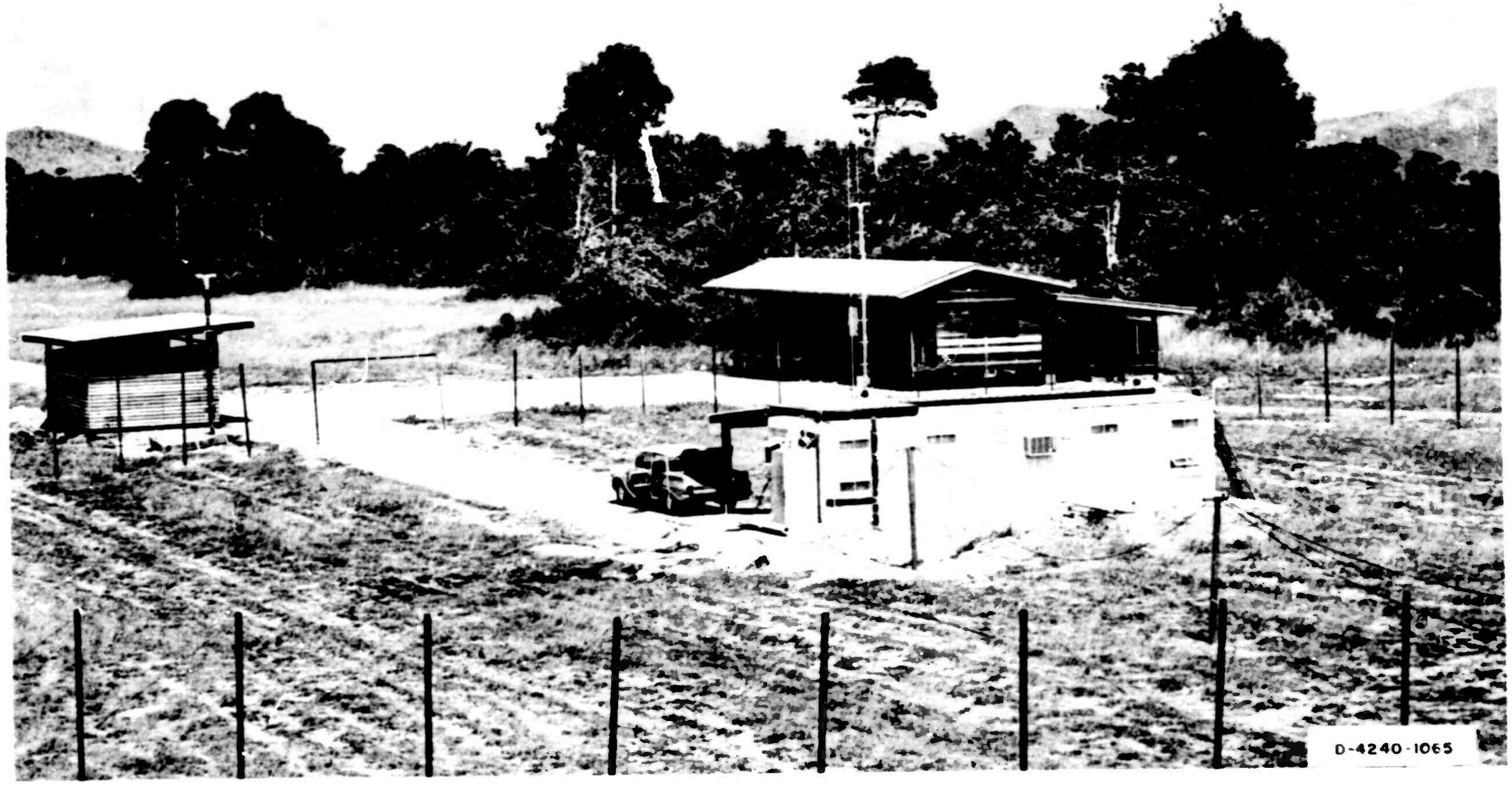


FIG. 2 THE OVERALL LAYOUT OF NOISE-MEASURING SITE AT LAEM CHABANG

shelter at the left side of the photograph. Housing is provided for the operators and guards at the site to permit 24-hour operation when required. The antenna installation is shown in more detail in Fig. 3. The standard 6.63-meter vertical antenna is located on the top of the equipment van, and at the bottom of the antenna is a copper plate used for mounting a ground screen of 90 radial copper wires. These radial wires screen the antenna electrically from the influence of local earth conditions. This installation of monopole and screen is identical with those employed at all the noise measurement stations in the worldwide ARN-2 network. In addition to this antenna ground screen, a lightning arrester made of a small copper tube was also set up to protect the antenna system from lightning strokes.

The noise-measuring equipment is shown in Fig. 4. It is a four-channel system which records the average noise power and the deviation of the average received noise voltage from the rms voltage simultaneously on two analog chart recorders. The basic purpose of the equipment is to measure noise in narrow bands; each of the four channels accepts a 200-Hz band of noise centered at either MF or HF. The equipment provides amplification over a wide dynamic range with an internal noise level that is small compared with the minimum atmospheric noise to be measured. Means are provided for calibrating the system by comparing the power level at the input terminals with a standard noise diode output. For a more detailed description of the equipment and its calibration, the reader is referred to Ref. 3.

B. Data Collection and Processing

Data charts are normally collected once a week and are taken to the MRDC-EL in Bangkok for processing. Each roll is about 30-feet long and contains calibration data, average-power and average-envelope voltage recordings for each of two frequencies in the VLF or LF bands and in the MF or HF bands. Two such chart recordings contain all the data generated by the ARN-3 equipment at Laem Chabang during one week. The typical data chart of Fig. 5 shows example recordings of noise voltage and noise power on two channels. The equipment channels are time-shared to collect data

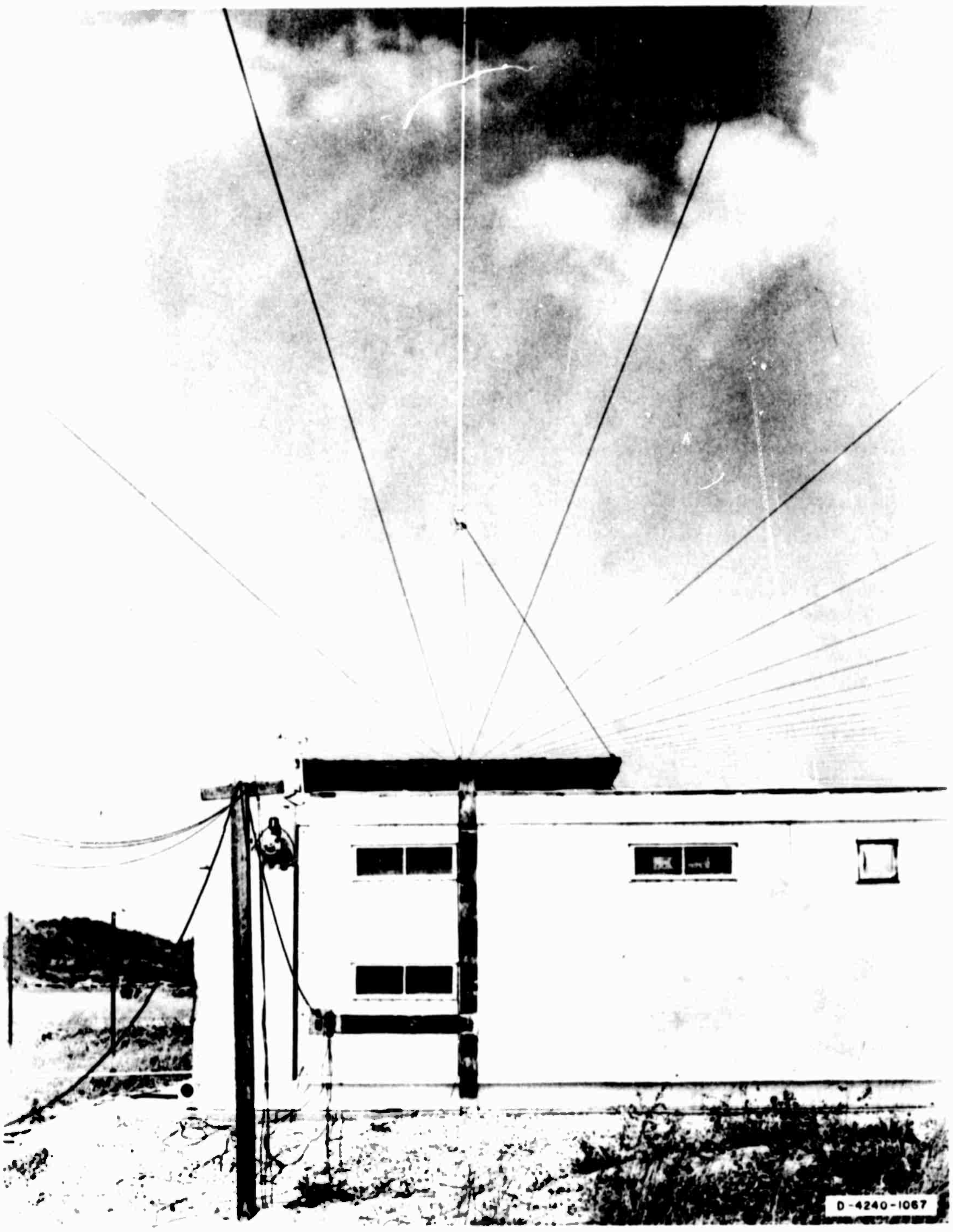


FIG. 3 ANTENNA FOR ARN-3 EQUIPMENT

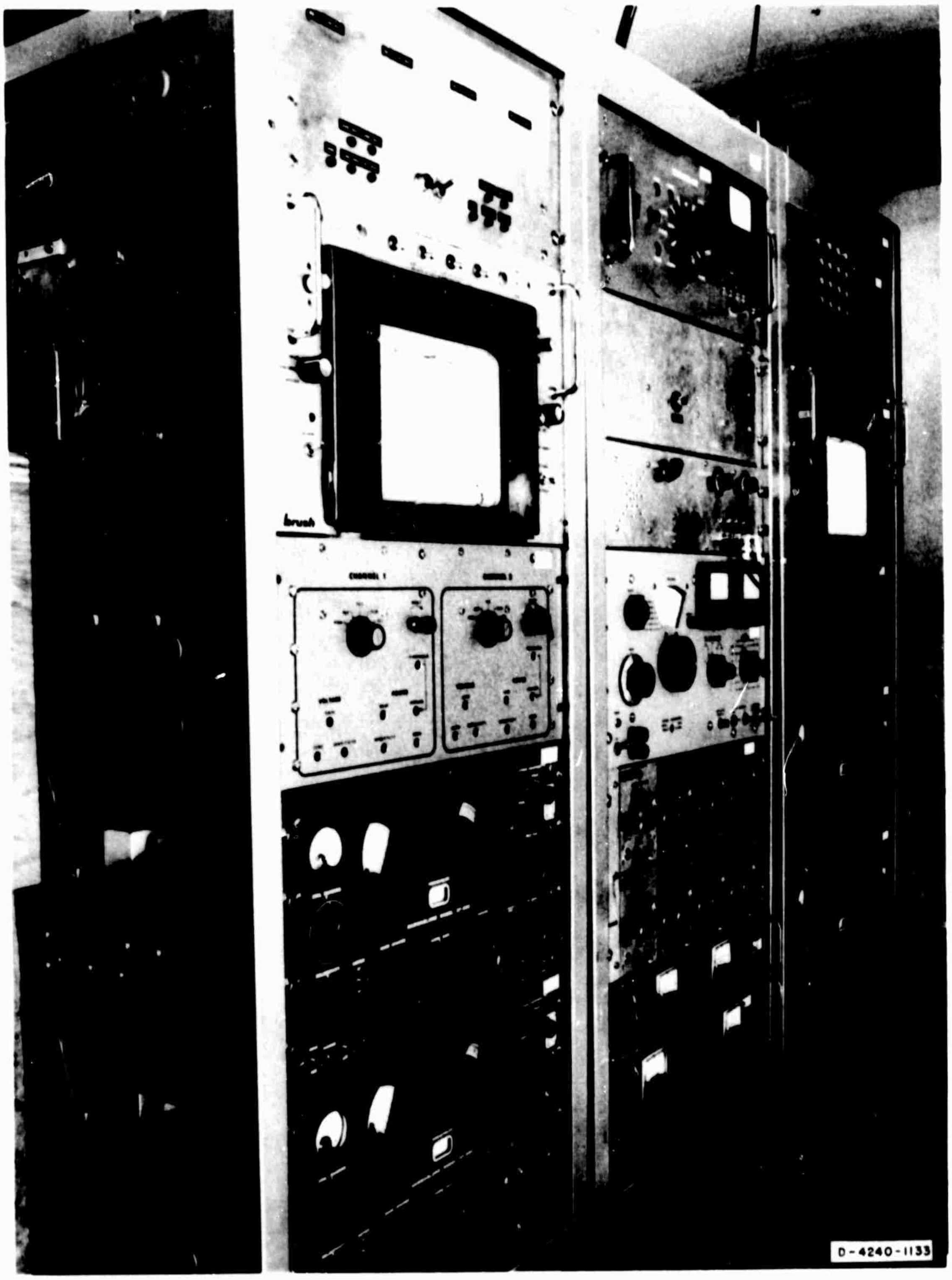


FIG. 4 THE ARN-3 NOISE-MEASURING EQUIPMENT

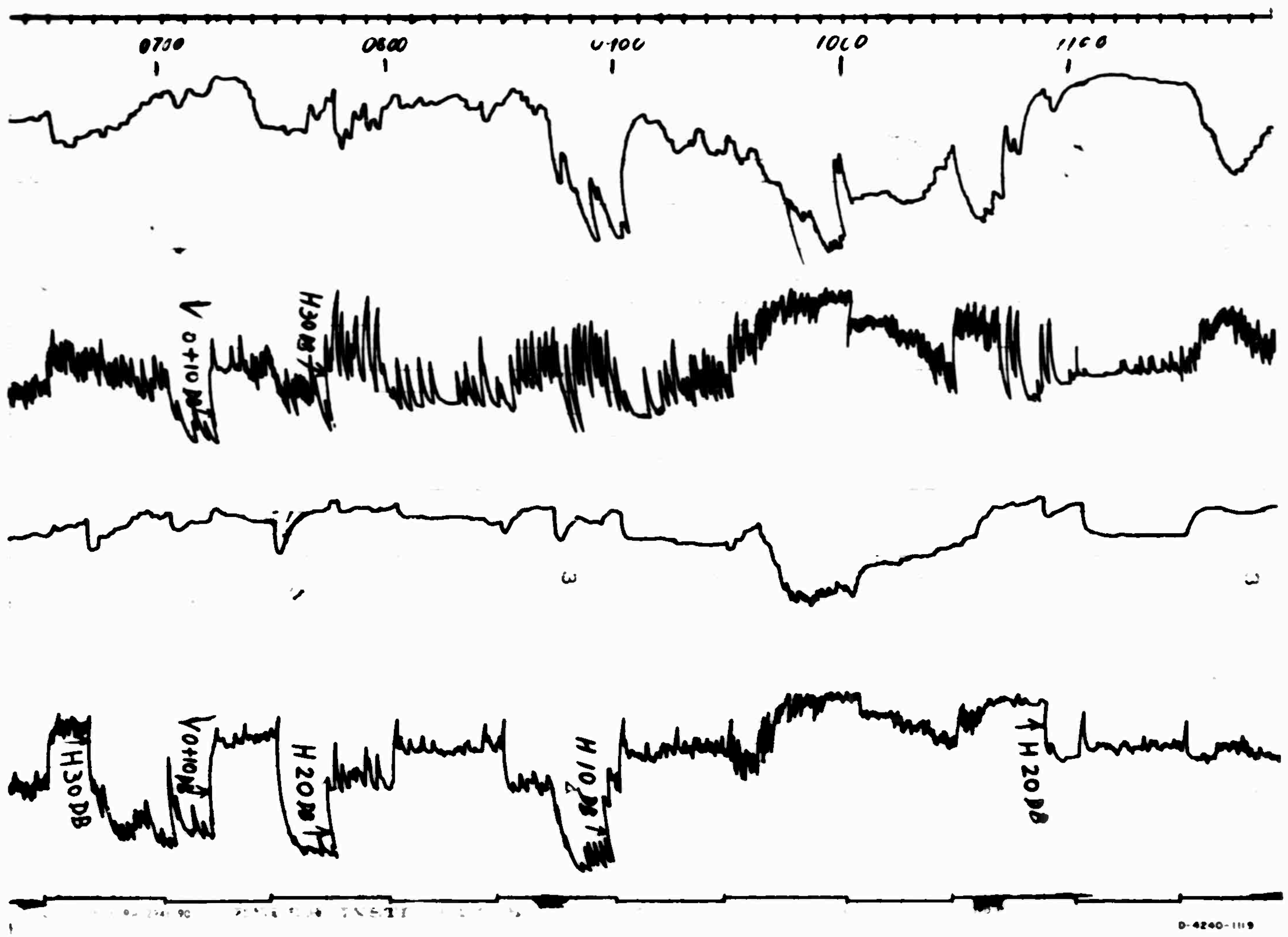


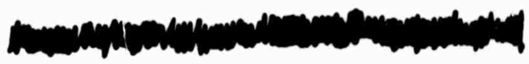
FIG. 5 TYPICAL DATA CHART

on LF and HF noise and are switched between the assigned frequencies once every 30 minutes. The trace of the event-marker pen on the right side of the record indicates the times at which the received frequency is changed. The time marks shown on the left-hand track are made at 6-minute intervals and indicate the actual local time of the measurement (GMT plus 7 hours). In addition to the power and voltage recordings, other information--such as the amount of attenuation being used at the time, notes regarding equipment shut-downs, or interference that cannot be avoided by retuning--is written on the chart by the operator.

Rules for Data Scaling

The value of the noise data depends critically on the ability of the equipment operator and the data scaler to separate the actual atmospheric noise from interfering signals. The operator monitors the noise from a loudspeaker and also observes the form of the chart recording. If any ~~made~~ man-made interference is detected, the operator attempts to avoid it by retuning the narrow-band receiver over a small range. If the interference cannot be avoided, the operator makes a note on the chart record. The data clerk is trained to recognize interference in the chart recordings and is instructed to read only those parts of the recordings that appear to be pure noise. A further check is made by the data supervisor who applies certain plausibility rules to the tabulated results.

In general the noise-power recordings that have been obtained fall into one of three types of records shown in Fig. 6. In order to ensure that only genuine atmospheric noise--not man-made interference--is read, only types A and B are scaled. Records showing severe interference, such as Fig. 6c, are ignored. In judging the pure atmospheric noise measurements, it would be helpful to bear in mind that the lowest level on the record will usually consist entirely of atmospheric noise, and that excessive deviations above the minimum are probably caused by interference. Considering only records like Figs. 6a and 6b, the data clerk carefully estimates by eye the magnitude of the 30-minute sample, takes into account system attenuation, and obtains a value of noise power that represents the hourly value for a particular hour, day, and frequency. The resulting numbers are tabulated on a special form, which is later checked by the



(a) ATMOSPHERIC NOISE WITHOUT INTERFERENCE

(b) ATMOSPHERIC NOISE WITH INTERFERENCE

(c) ATMOSPHERIC NOISE WITH
EXCESSIVE INTERFERENCE

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FIG. 6 TYPES OF NOISE-POWER RECORDS

data supervisor according to the following plausibility rules developed during the course of this work:

(1) Examination of the diurnal variation shows that the nighttime level of noise power is higher than the daytime level by about 15-30 dB for MF and HF noise.

(2) The hour-to-hour variation at all frequencies is (in the absence of local electrical storms) less than 10 dB.

(3) No sudden changes in noise-power level occur during the record period (in the absence of local electrical storms).

(4) The noise at 0.53 MHz is approximately 40 dB higher than that at 10 MHz for all times of day.

Because of the uncertainty of the form of the noise records, it is sometimes very difficult to classify a record according to Fig. 6. With

the measurement techniques and rules on data-chart scaling, many of the types of interference will be excluded. However, during daytime there will usually be a residuum of man-made noise from the local broadcast services (primarily harmonics).[14] At night, signals propagated from distant transmitters become predominant at the higher frequencies. If the interference comes from a local source, apparent noise powers 10-15 dB higher than the atmospheric noise level can be expected. Under these circumstances good atmospheric noise data can be obtained only by frequent tuning of the narrowband noise-measuring equipment. During the first full quarter of operation (Spring 1966), the equipment was monitored 24 hours a day and a listening check was made every 30 minutes on each frequency to detect the presence of interference. If interference was noted, the receiver was tuned over a narrow range to avoid it. Analysis of the data obtained showed that (a) unwanted signals (narrow-band, coherent radiation from man-made sources--primarily transmitters) were present about 22 percent of the time, and (b) with frequent retuning the interference could be reduced to a negligible level for all but about 7 percent of the total time.

The chart recording gives the relative noise power in dB which, when added to the appropriate calibration factor, yields the effective antenna noise factor, F_a. F_a is defined as the noise power available from an equivalent lossless antenna in dB above kT_ob (the thermal noise power available from a passive resistance at the reference temperature, T_o, which is about "room" temperature), where

k = Boltzmann's constant (1.38×10^{-23} Joules per degree Kelvin)

T_o = reference temperature, taken as 288° Kelvin

b = effective receiver noise bandwidth (Hertz).

The noise-power readings taken from the charts are converted[15] into F_a by the following relationship:

$$F_a = R + (K + S - D) \quad ,$$

where R is the mean-power reading scaled from the charts, K is a system constant, S is stub factor, and D is a diode factor. The K factor is constant for a given frequency, and the factors S and D are determined during the weekly equipment calibration.[2,3]

The hourly values of F_a are treated statistically as follows: for all the values of noise power at a given hour and a given frequency for one month (normally 25-30 observations), the monthly median (F_{am}) and the upper and lower deciles (values exceeded 10 and 90 percent of the time--D_u and D_l respectively) are calculated. In addition the data are averaged over longer periods in order to obtain estimates of the seasonal medians. These seasonal values of the median of average noise power--also denoted F_{am}--are obtained by averaging all month-hour medians within the three-month period that fall within specific four-hour time blocks.* The division of the year into seasons, as standardized by CCIR Report No. 322, is shown in Table I.

Table I

SEASONS FOR NOISE-DATA PRESENTATION
(NORTHERN HEMISPHERE)

Spring	March, April, May
Summer	June, July, Aug.
Autumn	Sept, Oct, Nov.
Winter	Dec, Jan, Feb.

The same six time blocks, defined as the four-hour periods 00-04, 04-08, 08-12, 12-16, 16-20, 20-24, local time are used throughout the year.

---

* The actual median for a given time block and season should be obtained by rank-ordering the 300 to 360 values (number of hours per time block times the number of days per month data were obtained times the number of months per season) by amplitude and selecting the middle value, but this involves another calculation. A reasonable estimate of the true median can be obtained by averaging the monthly medians for a given time block and season (average of 12 values), and this approach was used in this report as it was in NBS Technical Notes 18-1 through 18-16.[16]

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III RESULTS

The mean noise power F_a is a basic noise parameter used in describing the atmospheric noise level and is generally the most significant parameter used in relating the effect of the noise to radio communication system performance. Emphasis is placed in this report on the analysis of noise power measured at 0.53, 2.3, 5.0 and 10.0 MHz during the 24-month period between March 1966 and February 1968 inclusive. In this section, data are first presented to show the observed diurnal and seasonal variation of noise; later a comparison is made between observed and predicted noise, and (as a result) a method of correcting the CCIR Report No. 322 contour-map predictions for Thailand is developed.

A. Observed Noise Level

1. Diurnal Variation of Monthly F_{am} and Decile Bounds

The characteristic variation of atmospheric noise during the day and night is illustrated by Figs. 7 and 8, which show data for four frequencies for the month of August 1966. The solid curves in each figure represent the monthly median and the dotted lines indicate the upper and lower decile values. Two things are apparent from these figures: (a) the noise level at any time of day decreases significantly with an increase in frequency, and (b) a broad but definite minimum occurs during the daytime just before local noon. The magnitude of the difference in noise level between day and night ranges from about 20 to 27 dB for the month of August. These numbers are fairly typical of the behavior for all months. Statistics for measurements made during the 21-month period are given in Table II.* The statistical parameters in this table apply to

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* When this report was begun, only data for the period March 1966 through November 1967 were available, and these months form the 21-month period covered in Table II. Just prior to completion of this report, scaled hourly values for December 1967 through February 1968 (the last quarter of operation of the ARN-3 at Laem Chabang) became available, and these latest results have been incorporated where practicable.

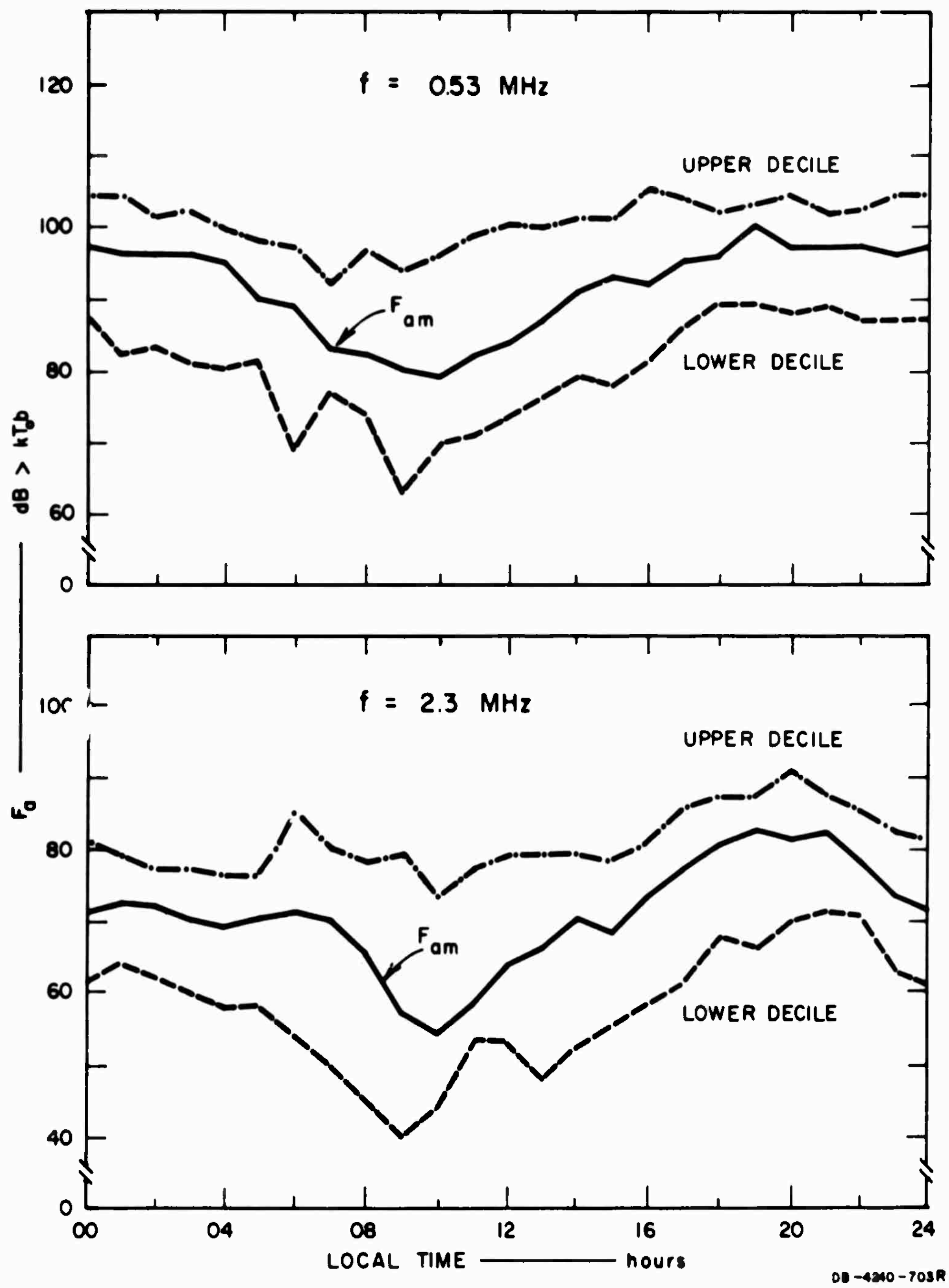

FIG. 7 TYPICAL DIURNAL VARIATION OF ATMOSPHERIC NOISE POWER FOR 0.53 MHz AND 2.3 MHz

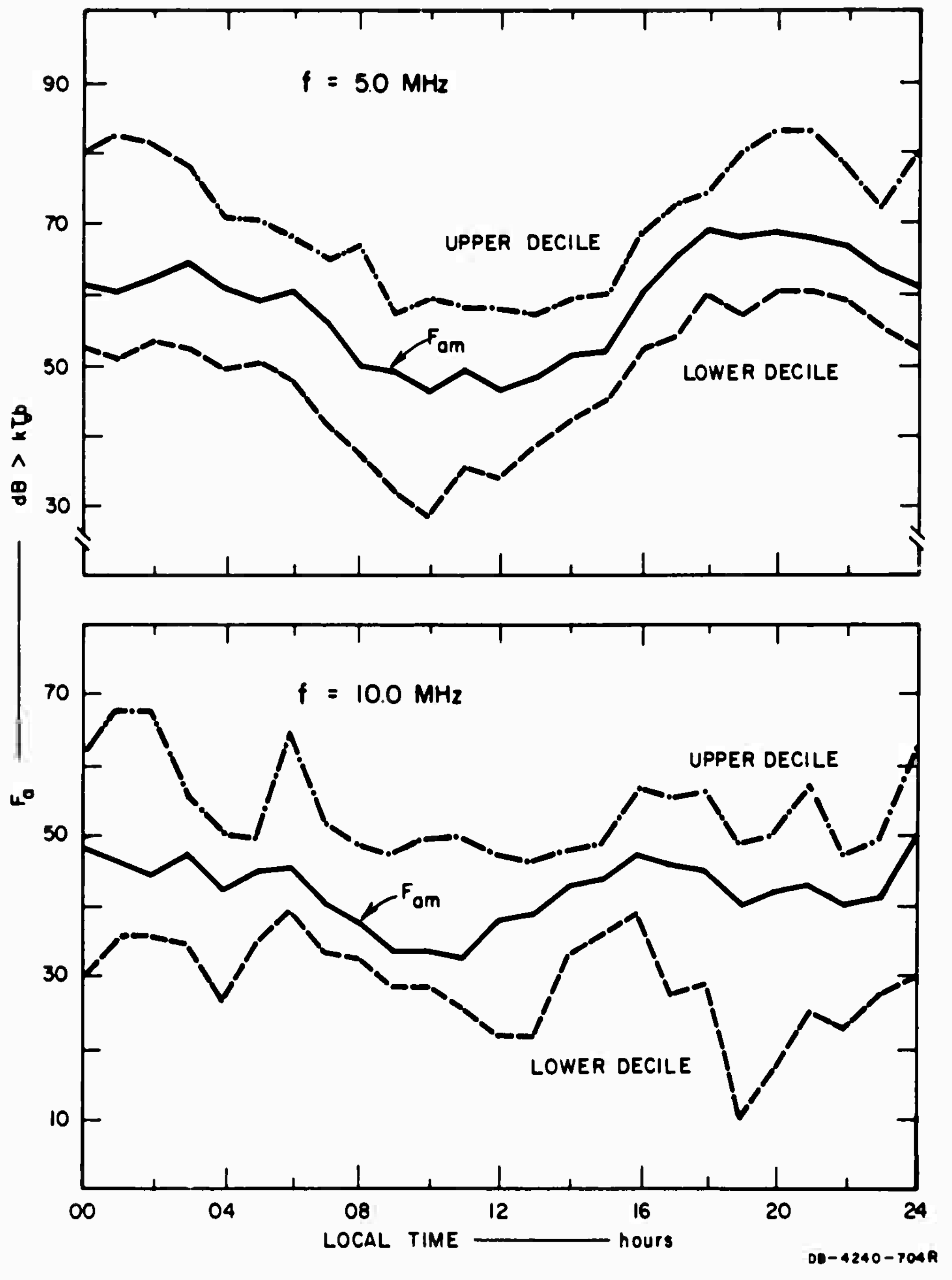

FIG. 8 TYPICAL DIURNAL VARIATION OF ATMOSPHERIC NOISE POWER FOR 5 AND 10 MHz

Table II

STATISTICS OF DIURNAL RANGE OF NOISE IN 21-MONTH PERIOD

Freq. (MHz)	Median (dB)	Upper Decile (dB)	Lower Decile (dB)
0.53	23	29	19
2.3	26	30	16
5.0	26	30	22
10.0	23	29	14

the distribution of 21 values of the monthly average of diurnal variation.* Analysis of the monthly average of diurnal range data does not reveal any significant seasonal trend.

The extent of the variation of noise for a given hour and frequency is indicated by the decile curves as shown in Figs. 7 and 8. From these figures it can be seen that 80 percent of the measured noise levels fall within a band of between 15 and 30 dB around the median value. If the difference between the upper and lower decile is calculated for each frequency and each hour from the monthly data given in the data reports,[6-12] the spread of measured noise can be obtained in terms of decile range. The medians of decile range values obtained in this way for 21 months of data are plotted against hour of the day for each frequency in Fig. 9. It will be observed that for 0.53 and 2.3 MHz there is a definite increase in the spread of the noise during the daytime. There is a decrease in decile range at 5 MHz during the morning hours and a relatively small increase in early afternoon. At 10 MHz the decile range is about 20 dB for all times of day. If the decile range data are treated differently and a median of the values for all hours of the day for a given month is computed, the variation of the spread of the noise with season can be investigated.

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* The monthly average was obtained from data in the atmospheric radio noise data bulletins.[6-12] For each frequency and each month the column of hourly median value of noise power was scanned and the difference between the largest and smallest number was calculated. The median and the decile values of the numbers obtained in this way for the 21-month period appear in Table II.

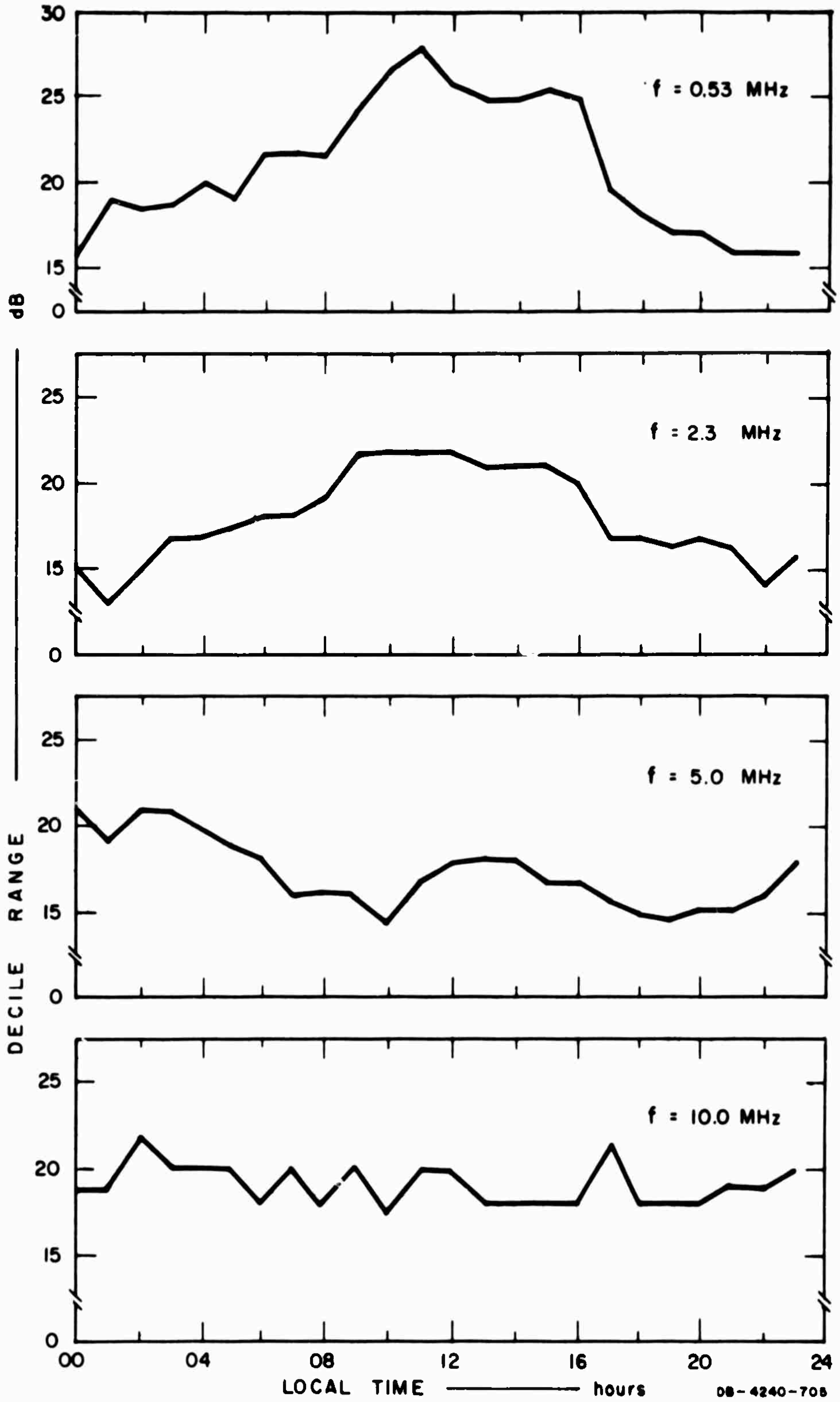

FIG. 9 THE MEDIAN OF DECILE-RANGE VALUES OF NOISE

Such an analysis does not show any correlation of data spread with season at any frequency. However, for all frequencies the median decile range decreases with calendar time, indicating that as the equipment operators and data scalers became more experienced, the extreme values of observed noise (probably man-made interference) were excluded during data reduction.

From the above analysis one can conclude that the average variation of noise from day to night is approximately 25 dB and that the average decile range of noise about the median is typically 20 dB at any given time. Having established the degree of spread of the measured noise data about the median value, we shall consider only median noise power (or averages of median noise power) in the remaining discussion.

2. Monthly and Seasonal Variation

Additional month-hour median data are shown in Fig. 10 for three months, June through August 1966. The diurnal trend and the variation of noise with frequency observed in Figs. 7 and 8 can also be seen here, but it will be observed that the hour-to-hour variations tend to hide the longer period variation of the actual atmospheric noise. In order to see

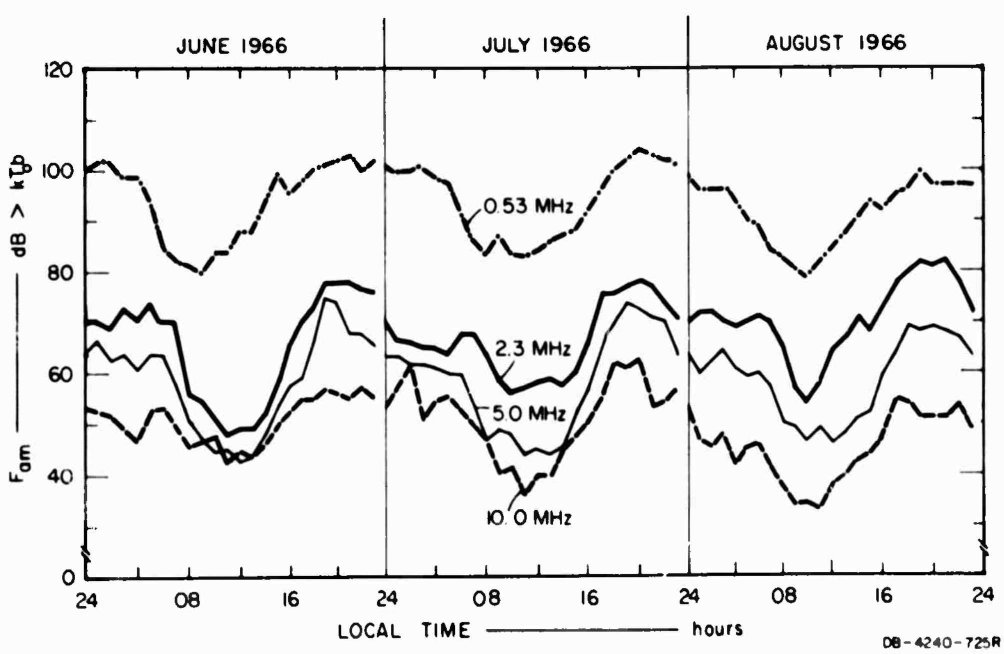

FIG. 10 TYPICAL DIURNAL VARIATION OF MONTHLY MEDIAN HOURLY VALUES OF ATMOSPHERIC NOISE POWER

these variations more clearly and to be able to compare measured data with predictions obtained from the CCIR noise contour maps (which are given by season and four-hour time blocks), it is desirable to present the data in a smoother form. Therefore, F_{am} as the average value of month-hour medians in the given four-hour time blocks for the June-August 1966 quarter is shown in Fig. 11. These curves still show plainly the variation with time of day and with frequency.

Data for the entire period of measurement are given in quarterly time-block values in Fig. 12. In addition to showing diurnal variations, Fig. 12 also indicates a variation of noise level with season. This trend can be seen more clearly in Fig. 13, which plots for each frequency the value of noise in each quarter for the 2000-2400 time block (noisiest period of the day) against season. Based on the relatively small amount of seasonal data, it appears that the quietest season is winter (December, January, and February). The data for 1966 indicate maximum noise during the spring season (March, April, and May), with decreasing noise in the summer and fall seasons. In 1967 there is an abrupt increase in noise during the spring season, followed by only a small decrease during summer, and then by a resurgence of noise in the fall. Plots of the noise in the 0800-1200 time block (quietest period of the day) and an average of noise in all six time blocks (not included in this report) show the same trend of noise power with season and similar magnitude of noise variation. We can conclude that the seasonal variation in noise power is of the order of 10 dB, but considerably more data are required to indicate whether either 1966 or 1967 is a typical year.

The dependence of magnitude of noise power upon frequency is shown generally in the previous figures. This relationship is illustrated more explicitly in Figs. 14 through 17, which show the average noise in each of the standard four-hour time blocks on a quarterly basis. In general, during the night, the variation with frequency is approximately linear (in dB), but during the daytime the rate of decrease of noise with increasing frequency is smaller above about 3 MHz than below. It will be observed that the shape of these curves depends somewhat upon the season of the year.

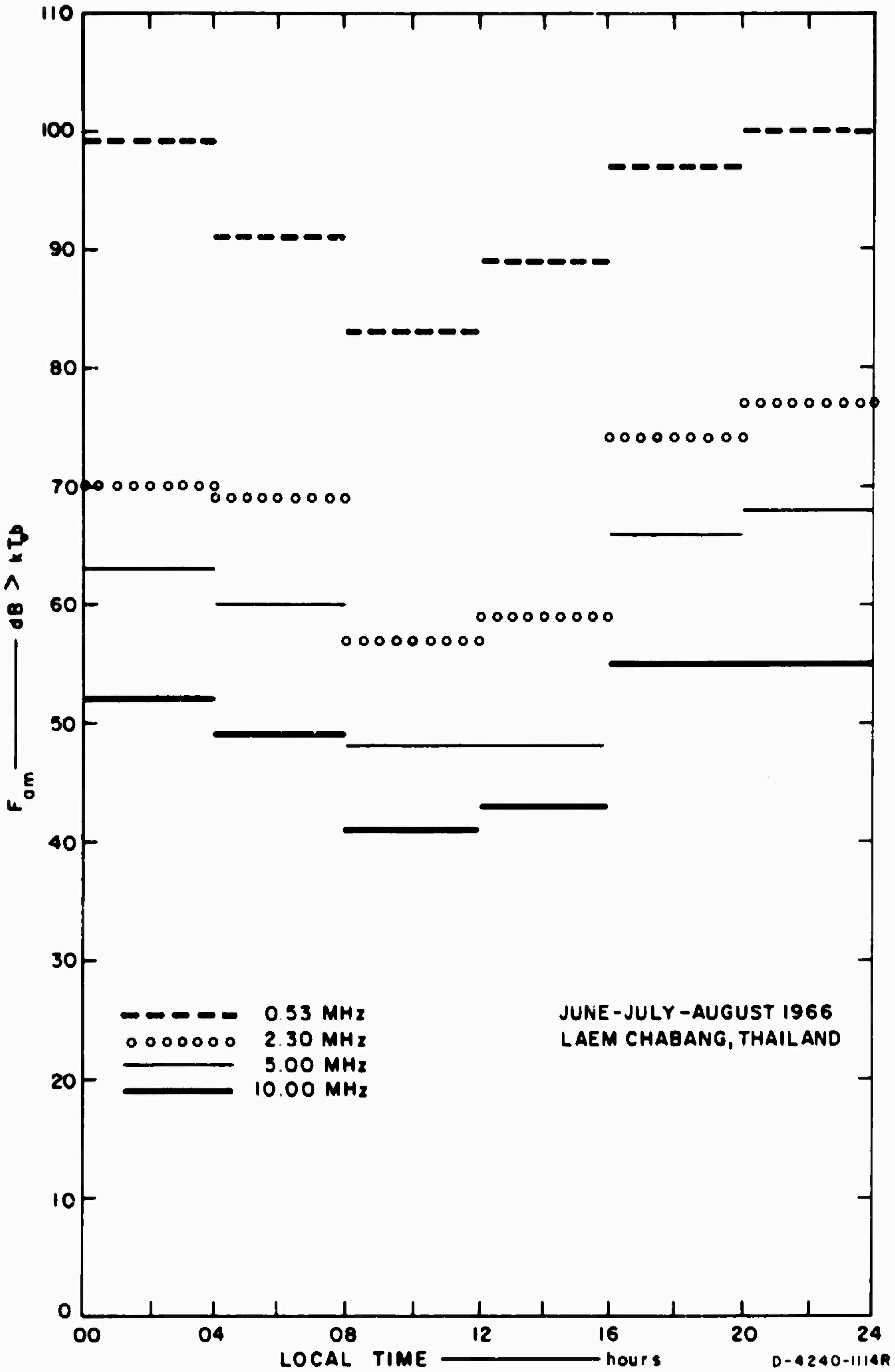

FIG. 11 TYPICAL SEASONAL TIME-BLOCK MEDIAN OF ATMOSPHERIC NOISE POWER

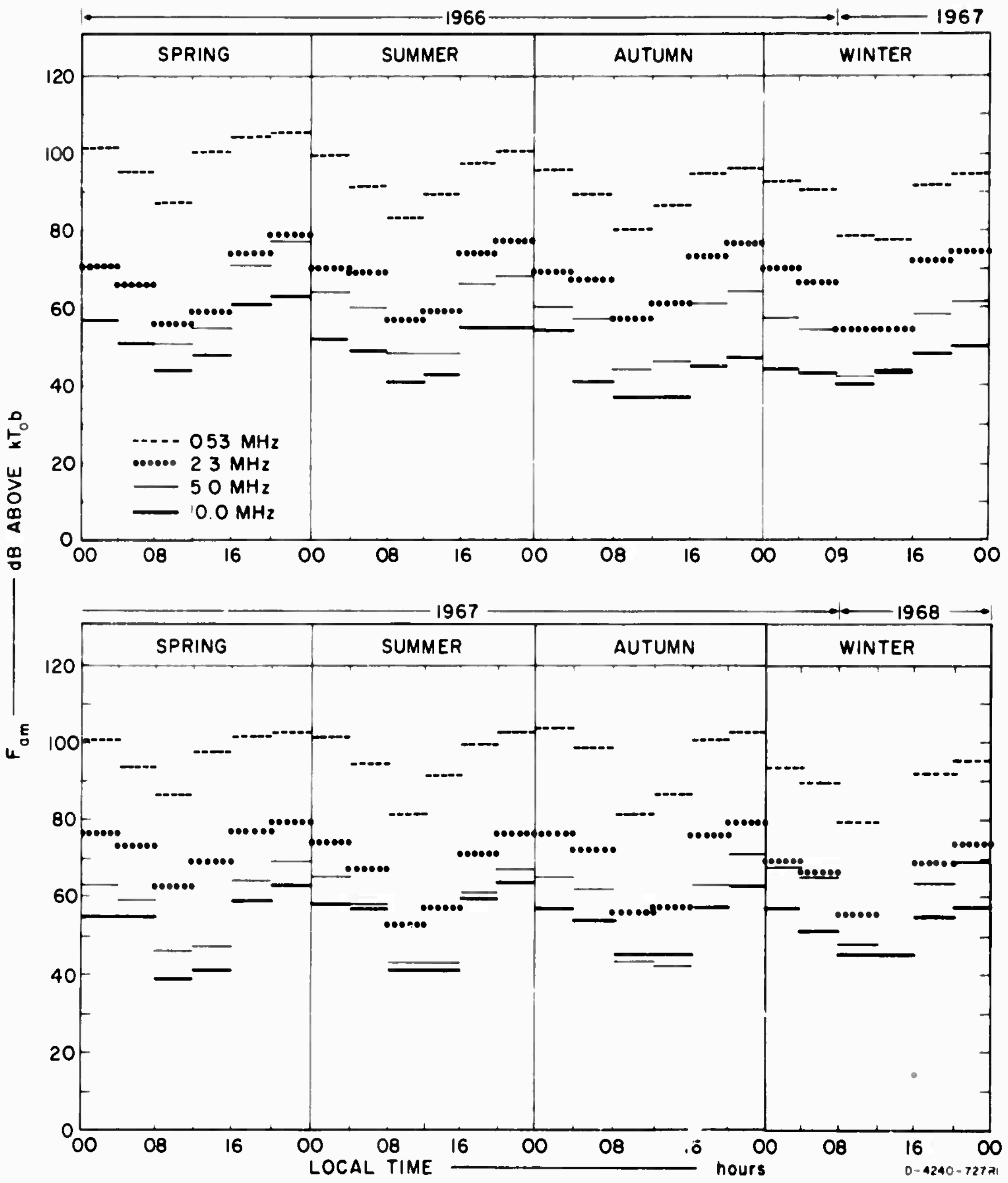

FIG 12 QUARTERLY TIME BLOCK MEDIAN OF NOISE POWER OBSERVED DURING THE PERIOD MARCH 1966 THROUGH FEBRUARY 1968

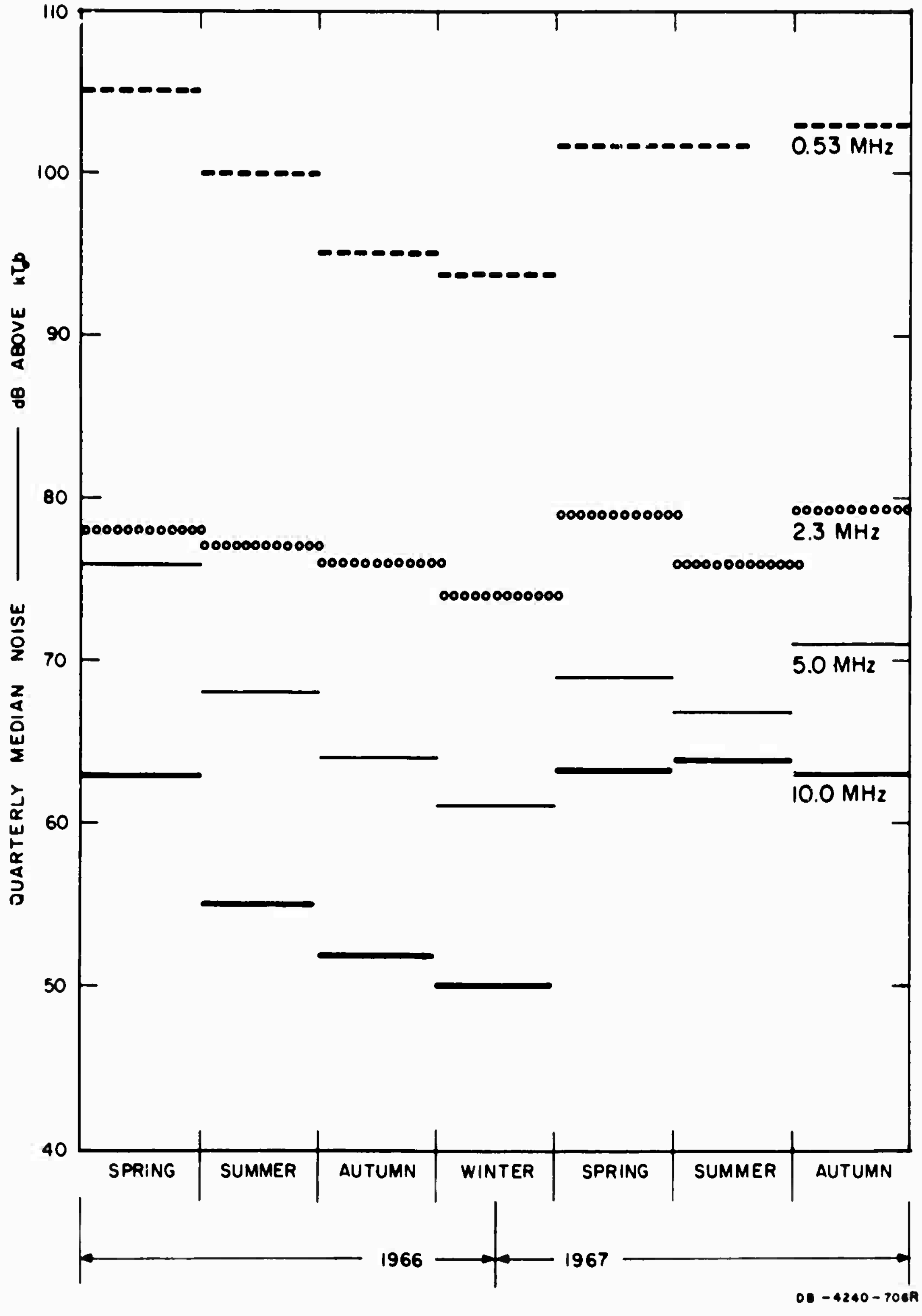

FIG. 13 NOISE OBSERVED IN TIME BLOCK 2000–2400 IN 1966 AND 1967

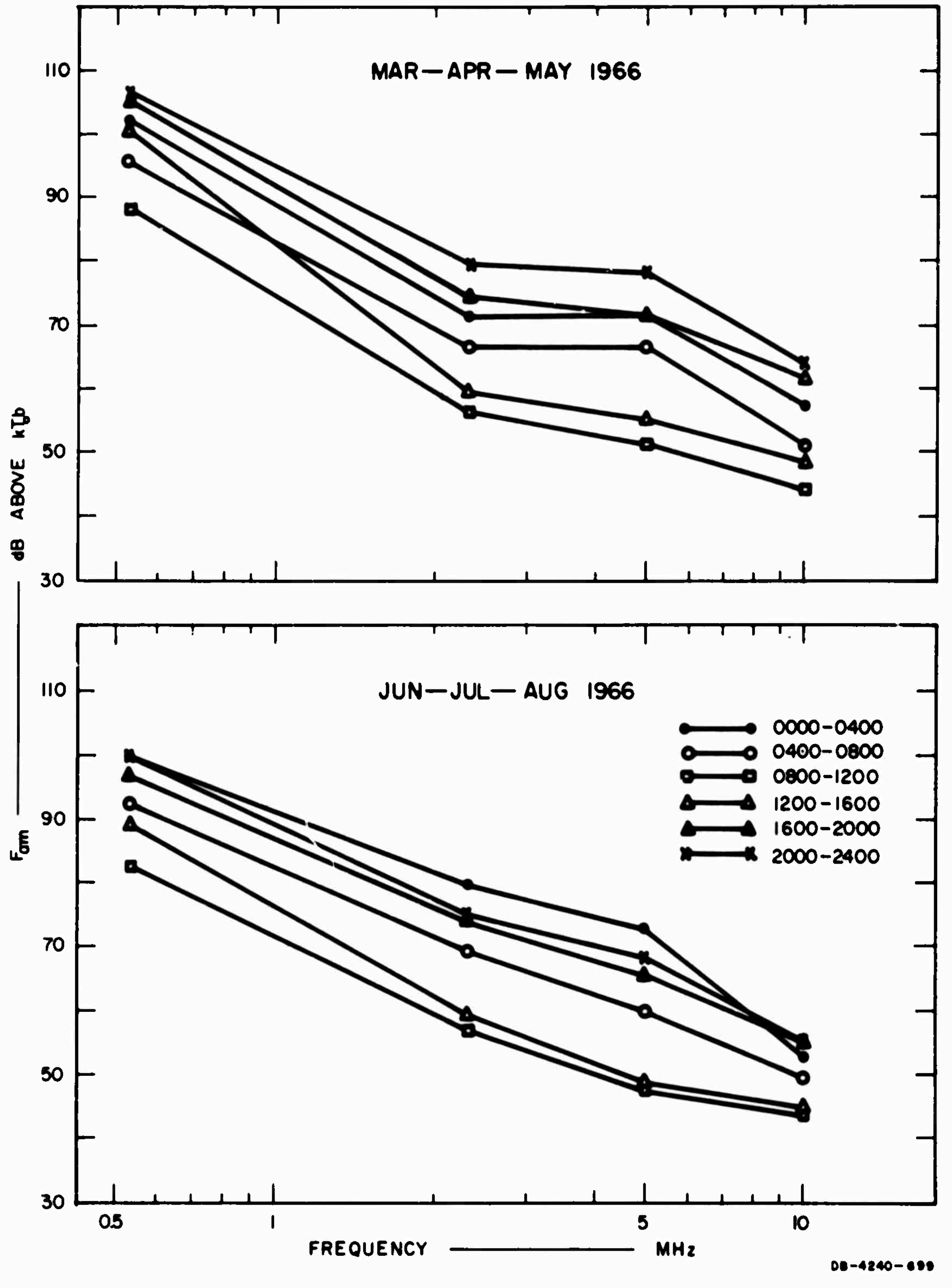

FIG. 14 FREQUENCY VARIATION OF NOISE POWER WITH SEASONAL TIME BLOCK FOR SPRING AND SUMMER 1966

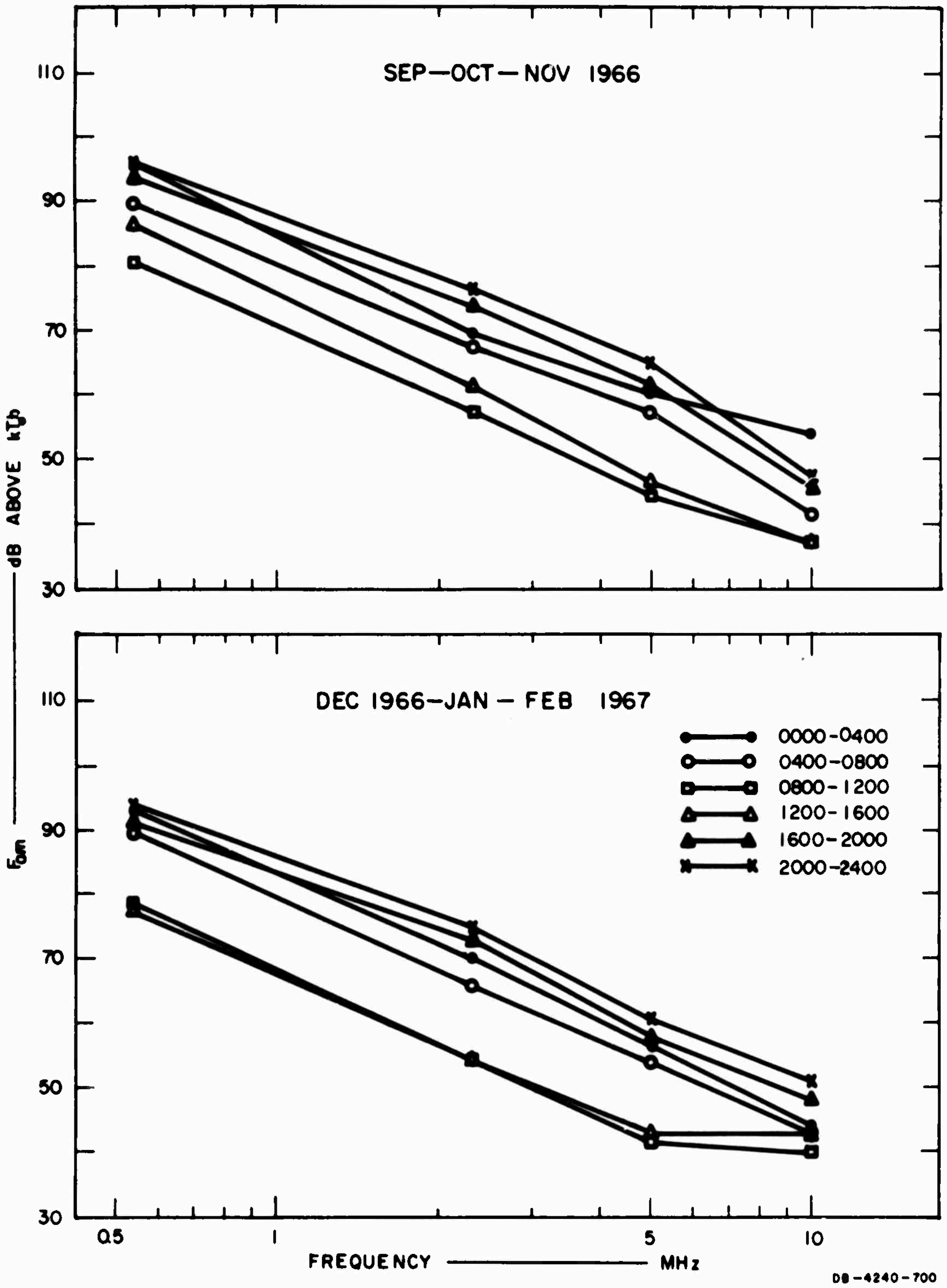

FIG. 15 FREQUENCY VARIATION OF NOISE POWER WITH SEASONAL TIME BLOCK FOR AUTUMN AND WINTER 1966

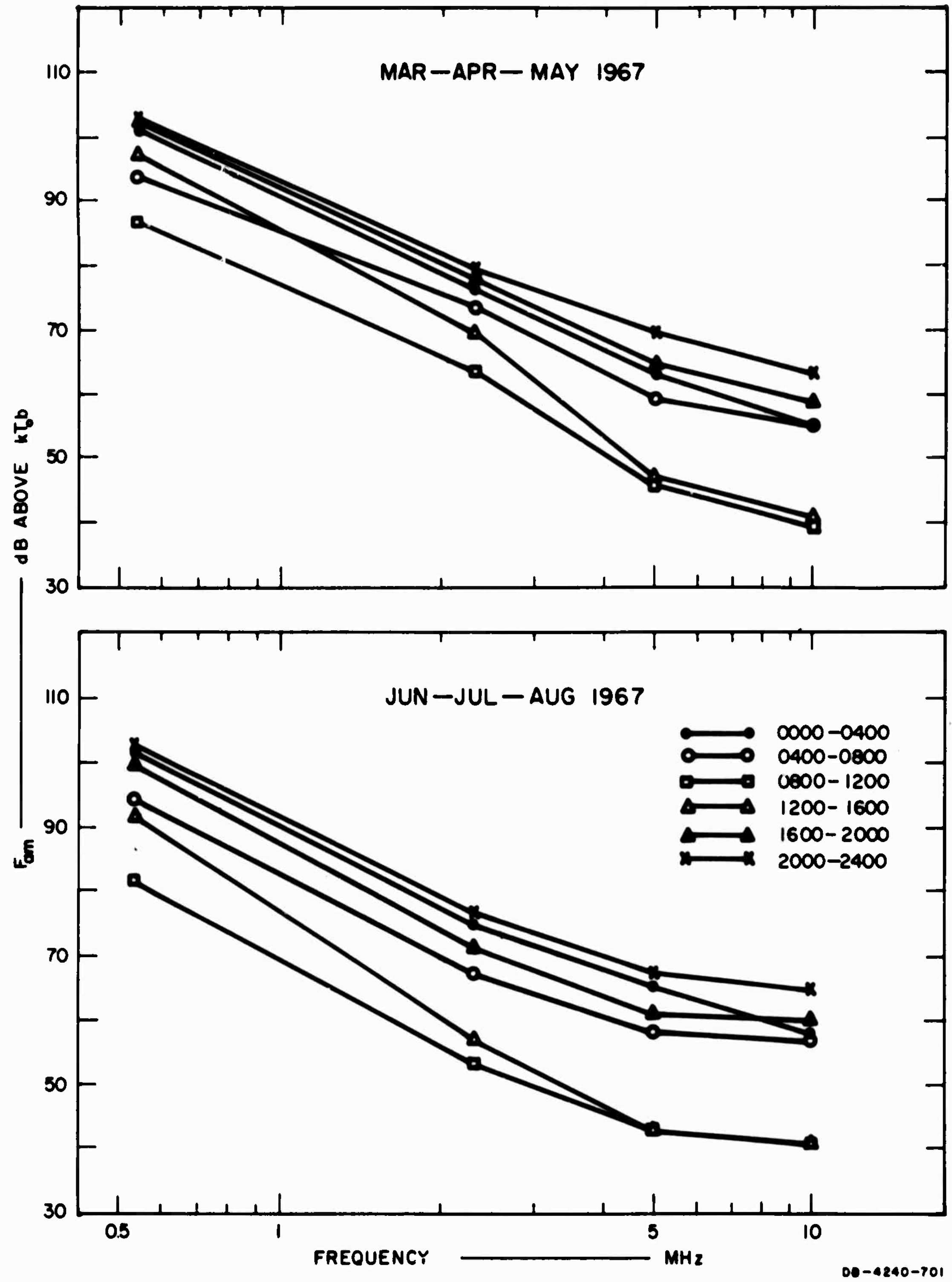

FIG. 16 FREQUENCY VARIATION OF NOISE POWER WITH SEASONAL TIME BLOCK FOR SPRING AND SUMMER 1967

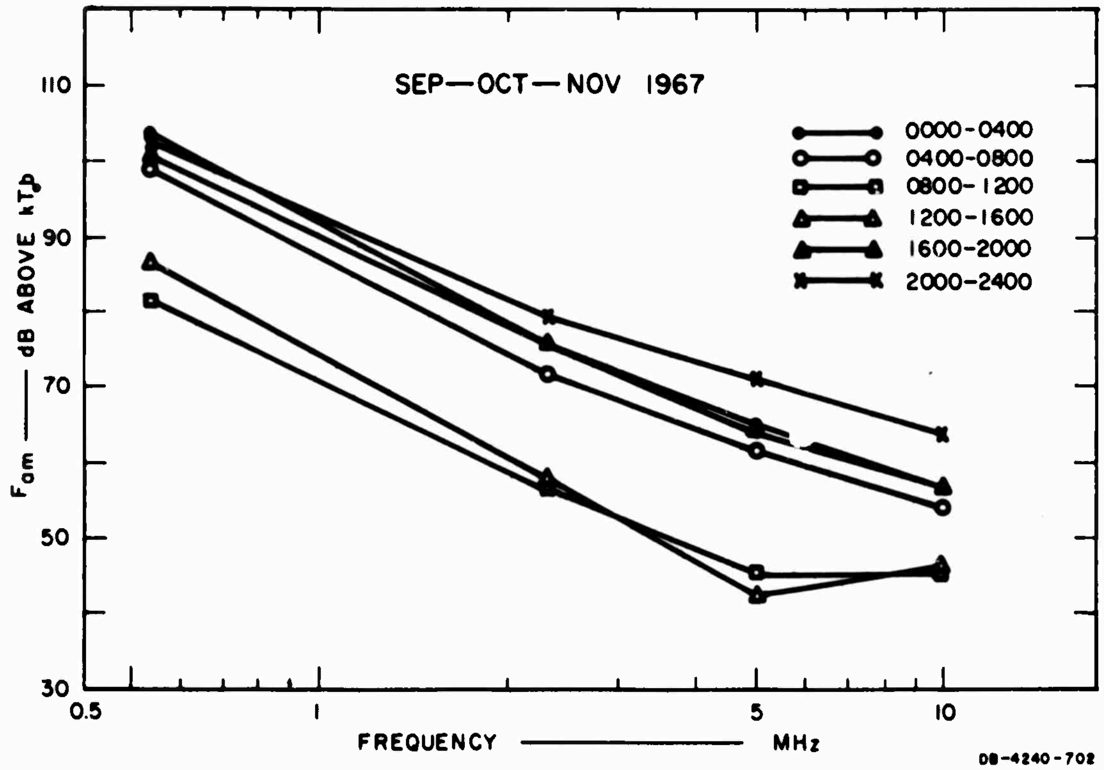

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FIG. 17 FREQUENCY VARIATION OF NOISE POWER WITH SEASONAL TIME BLOCK FOR AUTUMN 1967

B. Comparison of Observed Noise Power to CCIR Prediction

Expected values of the atmospheric noise power for any given geographical location and any particular time block and season can be determined by interpolating the contour noise maps given in CCIR Report No. 322 to obtain the noise power at 1 MHz in dB above kT_ob. By using a second set of curves (the B-series), the expected noise power for other frequencies can be determined. Since the noise measured at Laem Chabang is in the same units as the prediction values (i.e., the standard noise figure--F_{am}--in dB above kT_ob), results obtained from measurements can be compared directly with the CCIR prediction values for each observing frequency and seasonal time block.

Comparisons of observed and CCIR-predicted quarterly median noise power, F_{am}, obtained for Laem Chabang at frequencies 0.53, 2.3, 5.0, and 10.0 MHz, are plotted for March-April-May in Figs. 18-21. In these figures the noise values observed in 1966 and 1967 are separately compared with the CCIR prediction, and differences between the observed and predicted values are plotted in the lower part of the figures. A negative discrepancy (which we will define as prediction error) indicates that the predicted noise is lower than the observed noise. Data for the other seasons of the year are shown in Figs. 22 to 33.

This comparison indicates that the average of the month-hour medians of atmospheric noise power for a given time block and season observed at Laem Chabang for MF and HF was larger than CCIR predictions for more than 90 percent of the time. At lower frequencies (0.5 and 2.3 MHz) in the daytime, especially for the time blocks 0800-1200 and 1200-1600, the differences were greater than at nighttime (during time blocks 1600-2000, 2000-2400, 2400-0400, and 0400-0800). For the daytime, differences as great as 30 dB have often been found, but the median difference was about 14 dB. During nighttime, the difference rarely exceeds 15 dB and the median value is about 7 dB.

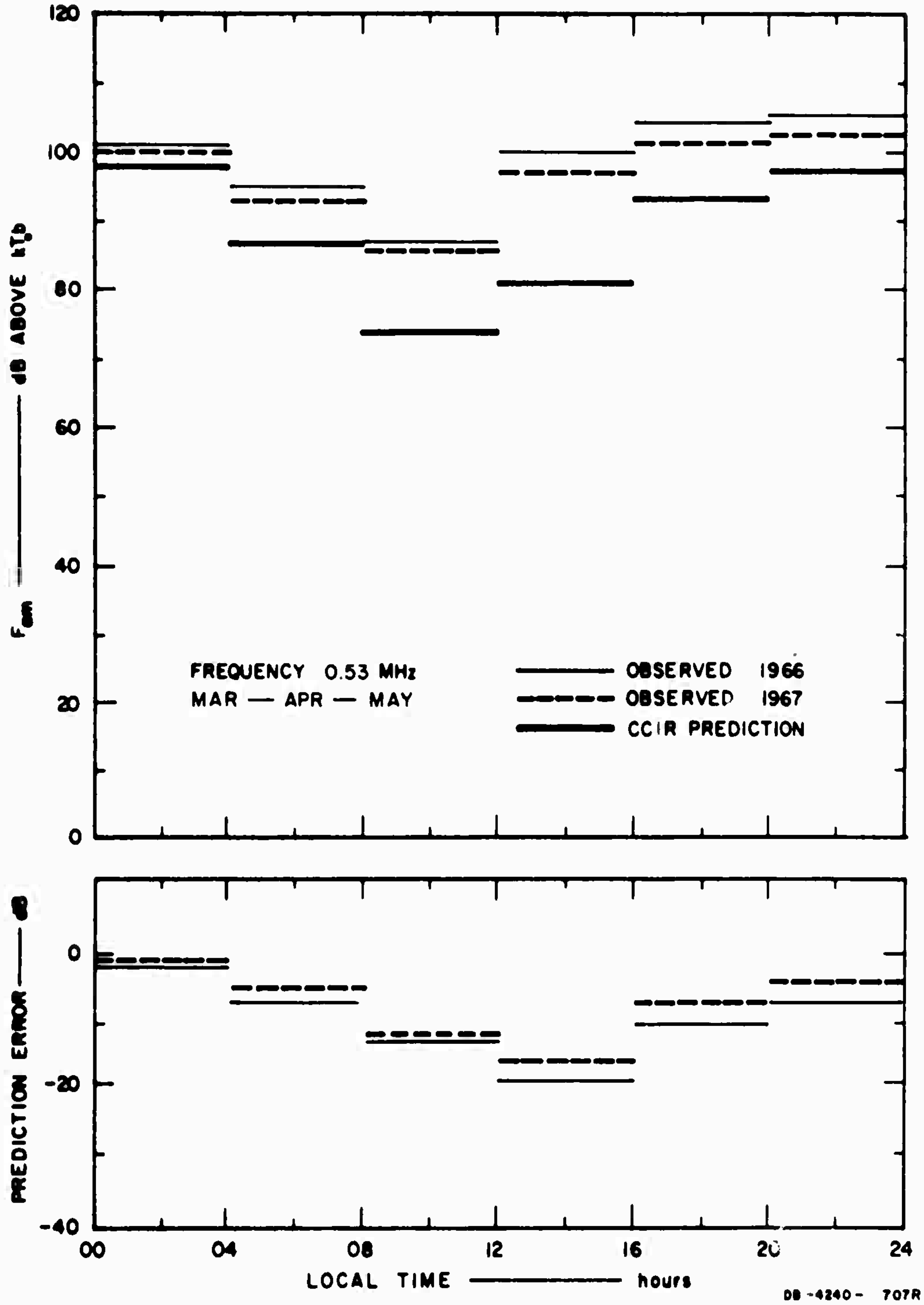

FIG. 18 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR SPRING 1966 AND 1967 — 0.53 MHz

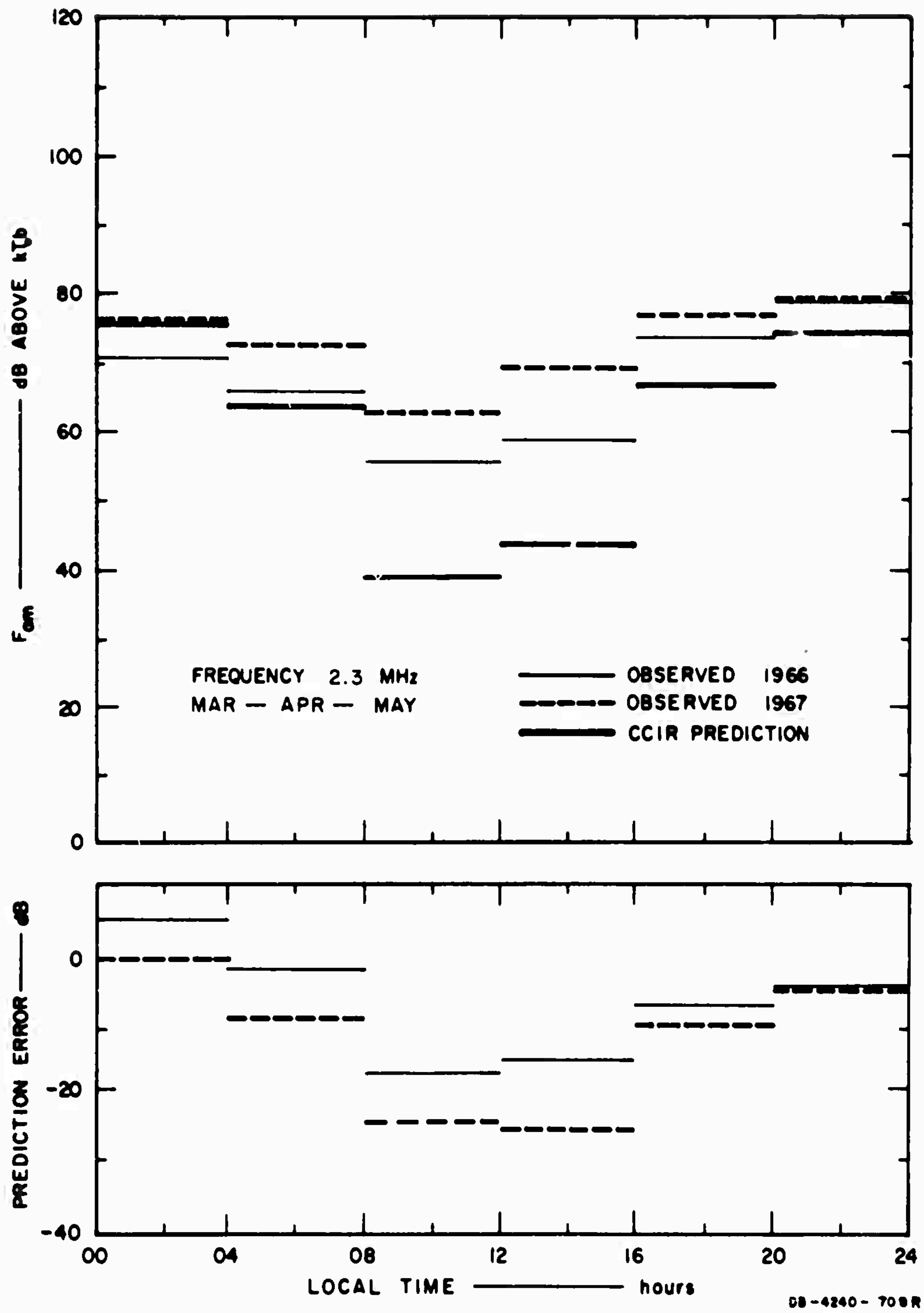

FIG. 19 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER F_{am}, FOR SPRING 1966 AND 1967 — 2.3 MHz

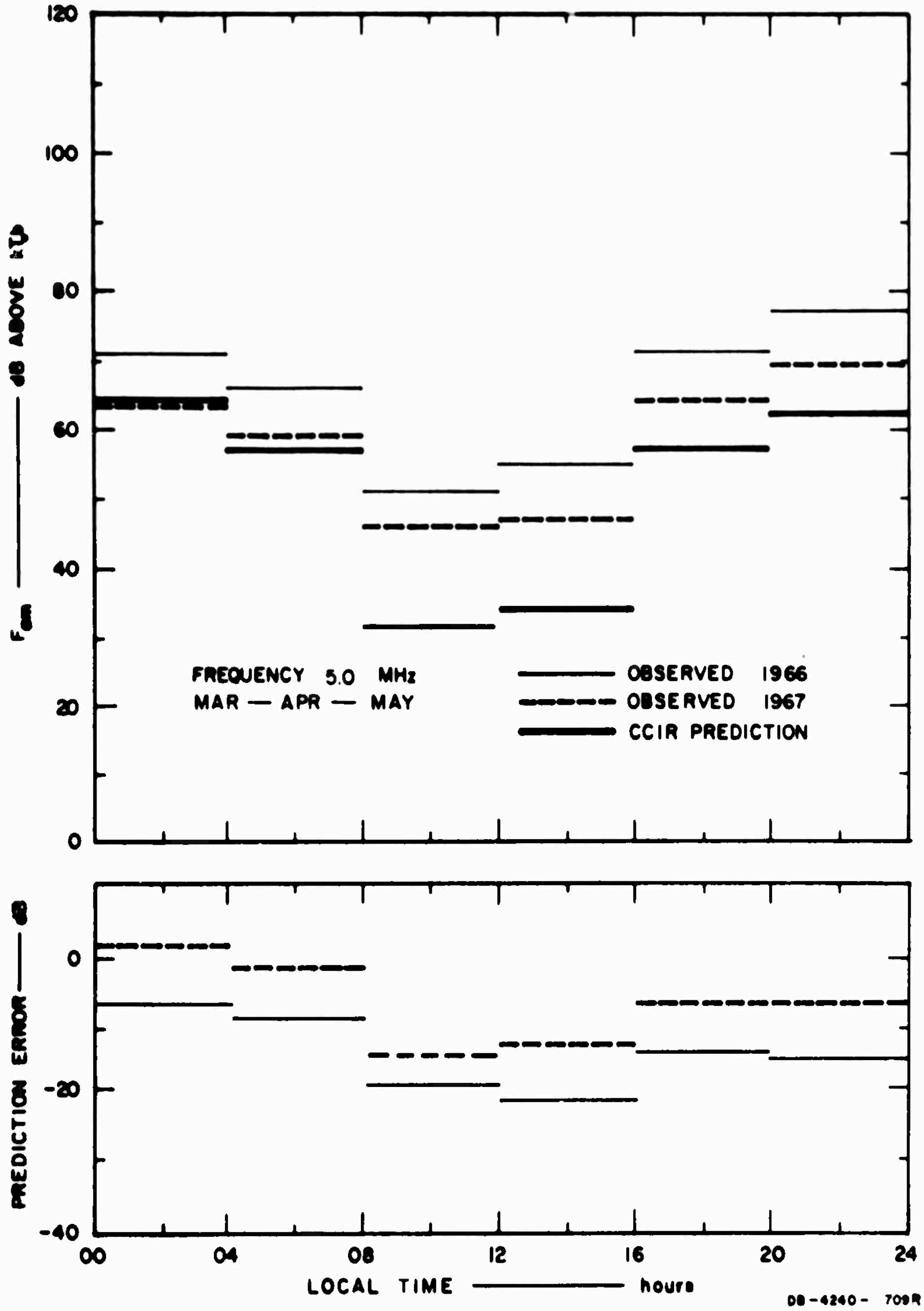

FIG. 20 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR SPRING 1966 AND 1967 — 5.0 MHz

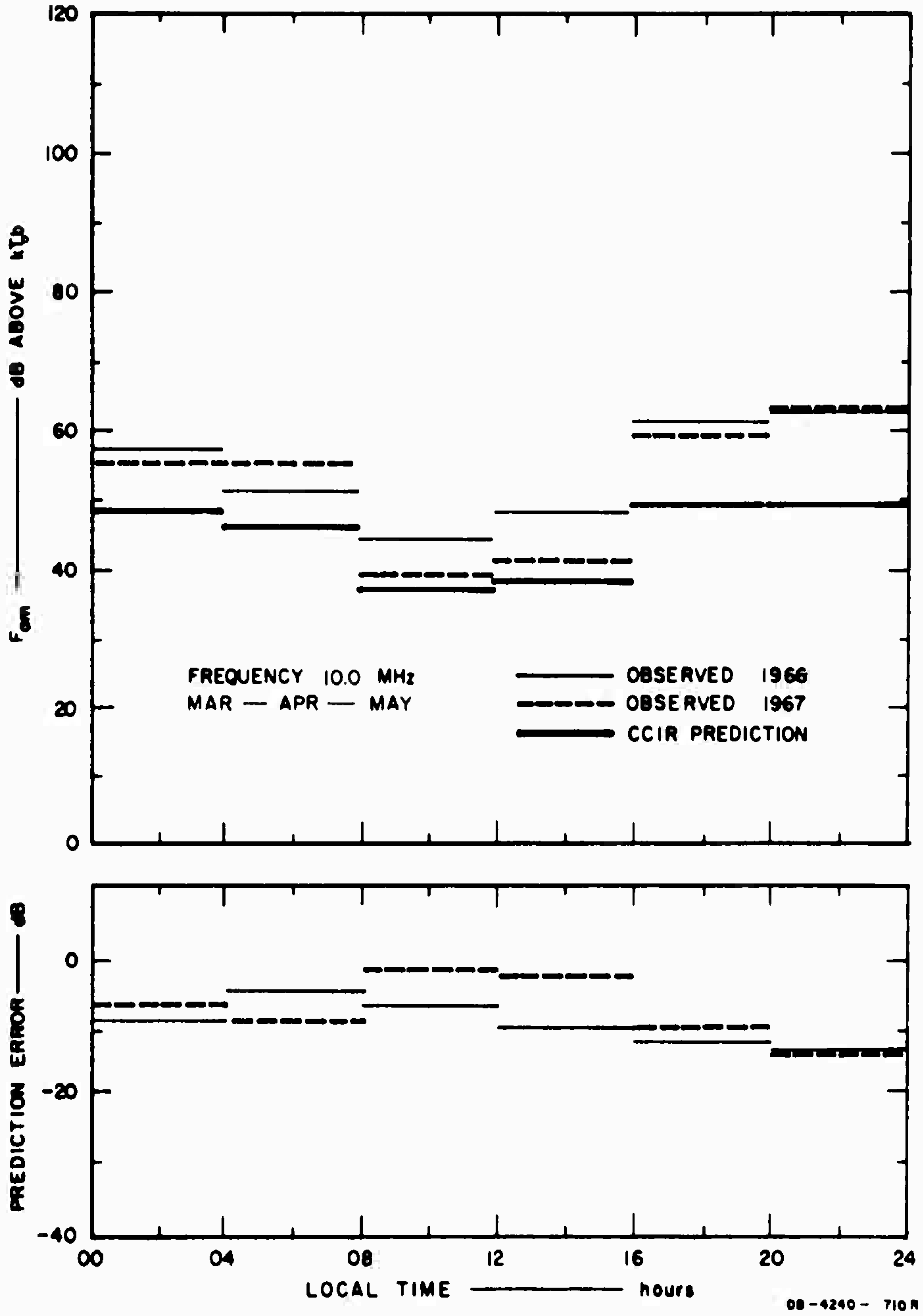

FIG. 21 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR SPRING 1966 AND 1967 — 10.0 MHz

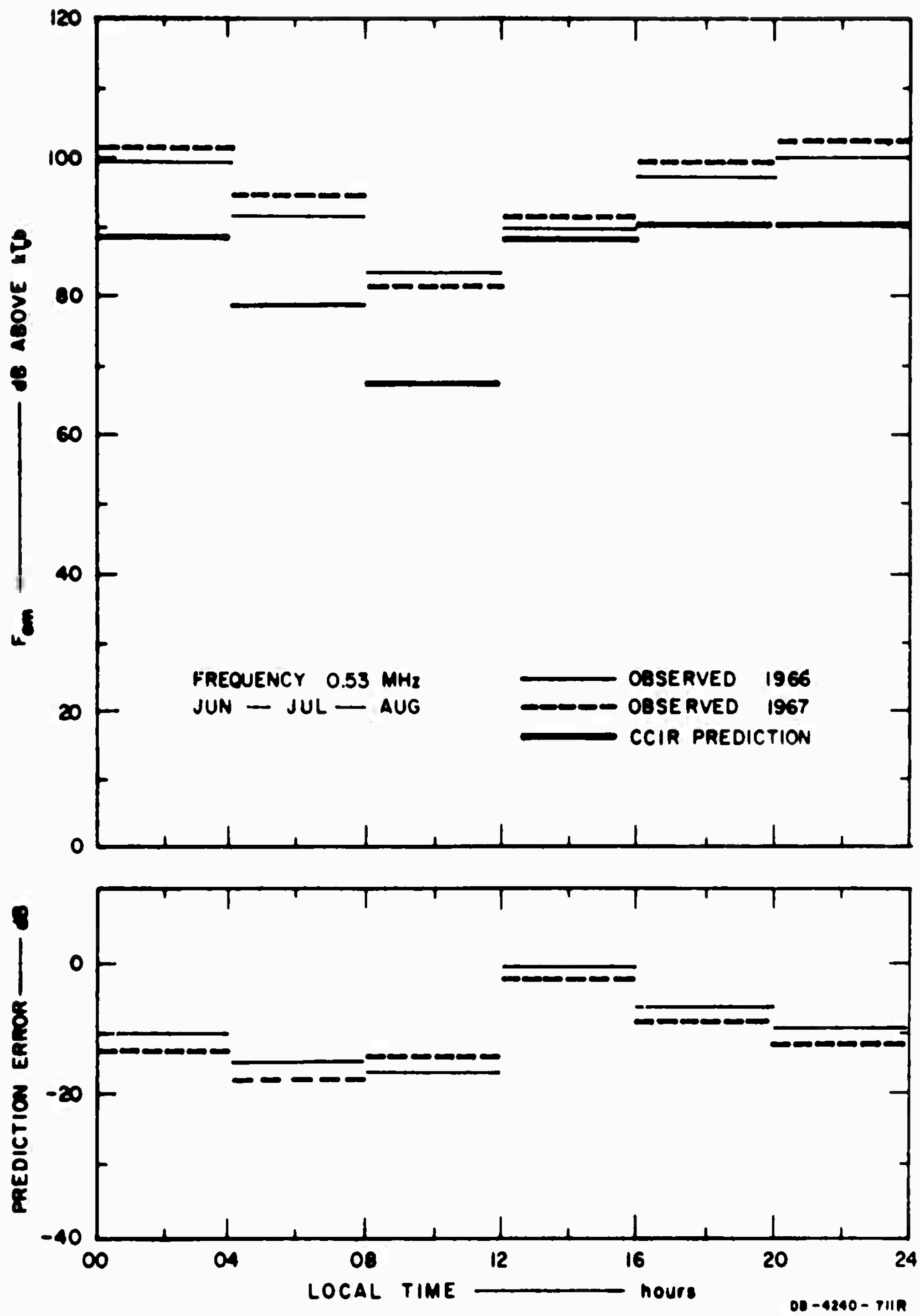

FIG. 22 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR SUMMER 1966 AND 1967 — 0.53 MHz

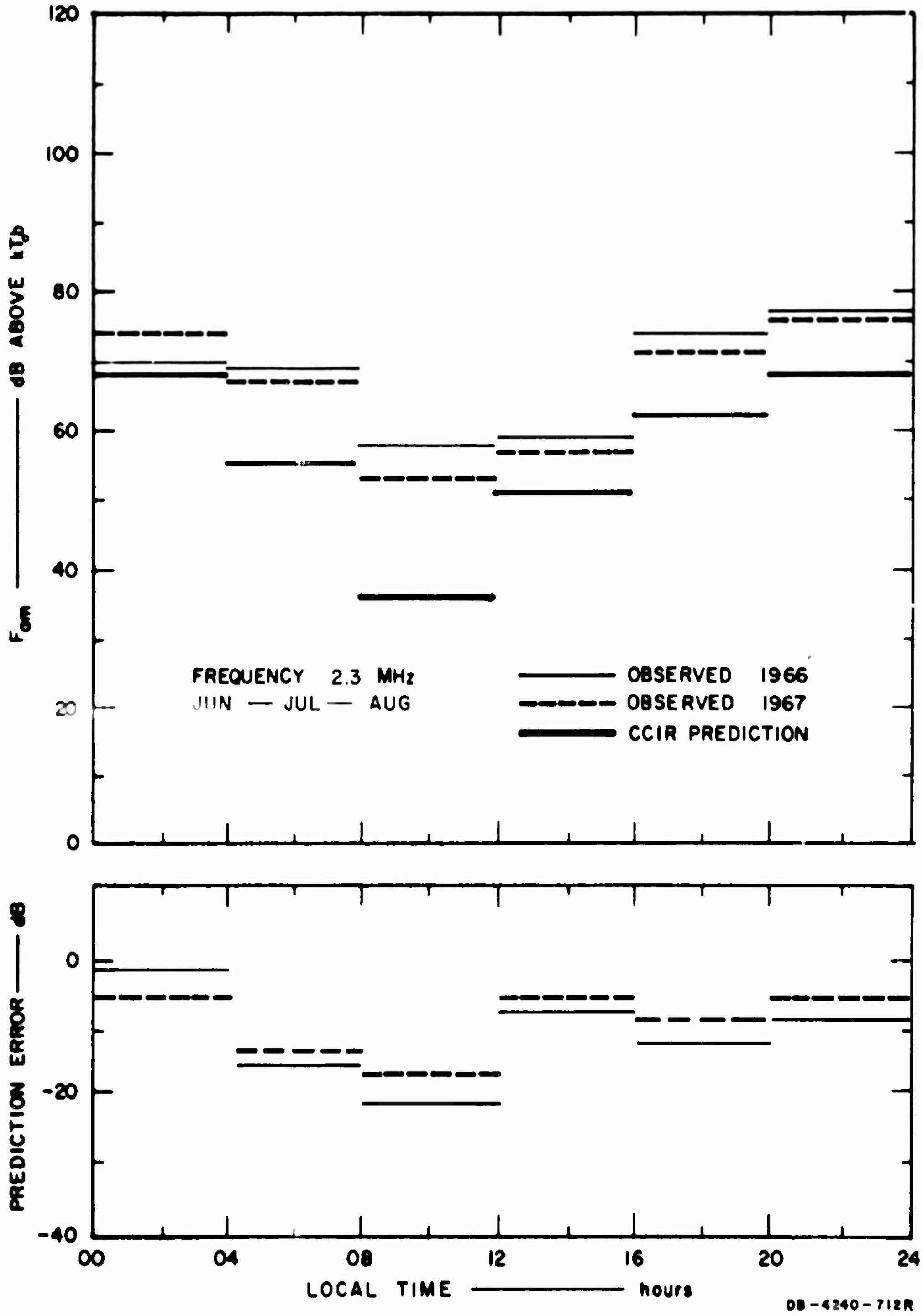

FIG. 23 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR SUMMER 1966 AND 1967 — 2.3 MHz

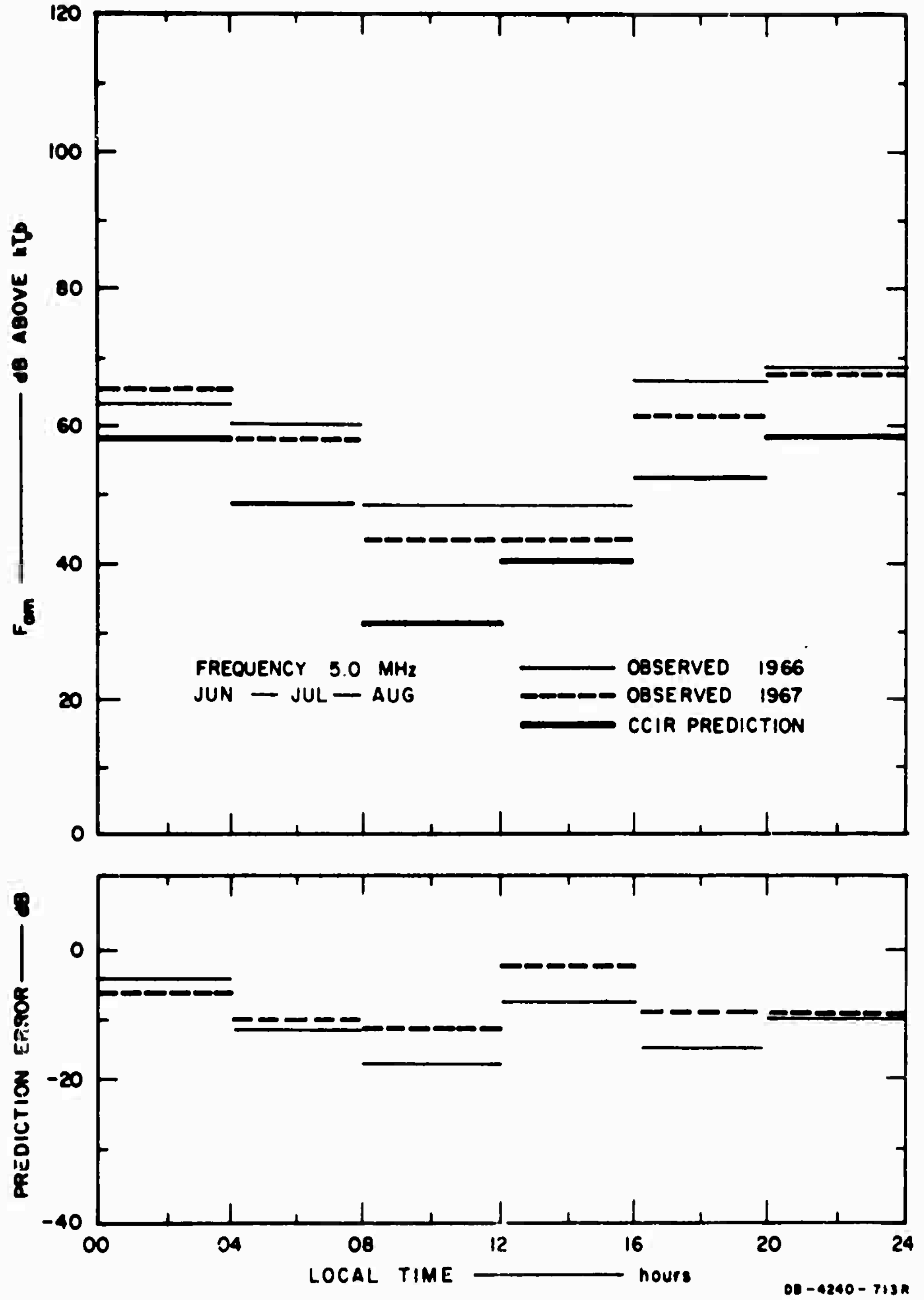

FIG. 24 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR SUMMER 1966 AND 1967 – 5.0 MHz

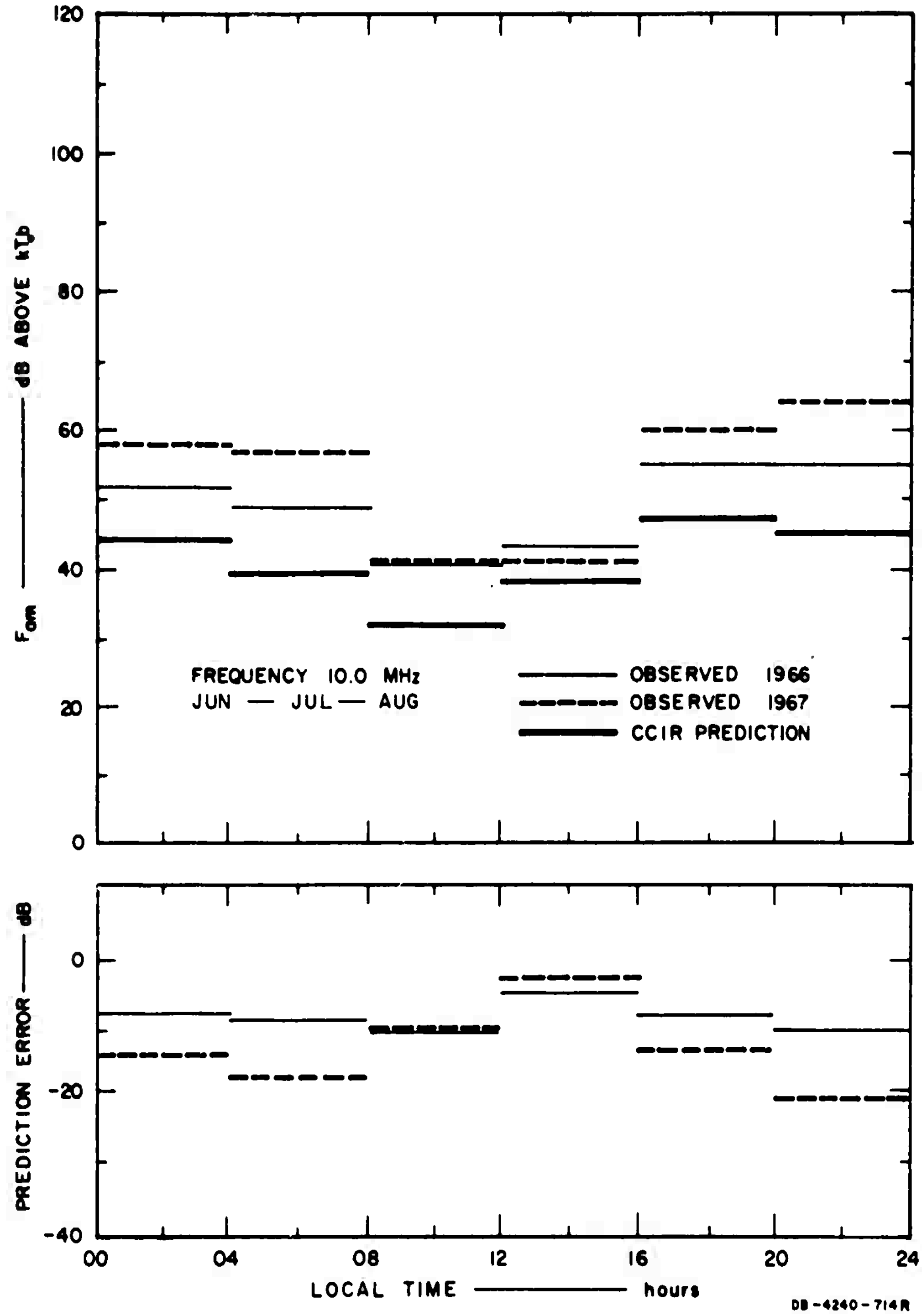

FIG. 25 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR SUMMER 1966 AND 1967 — 10.0 MHz

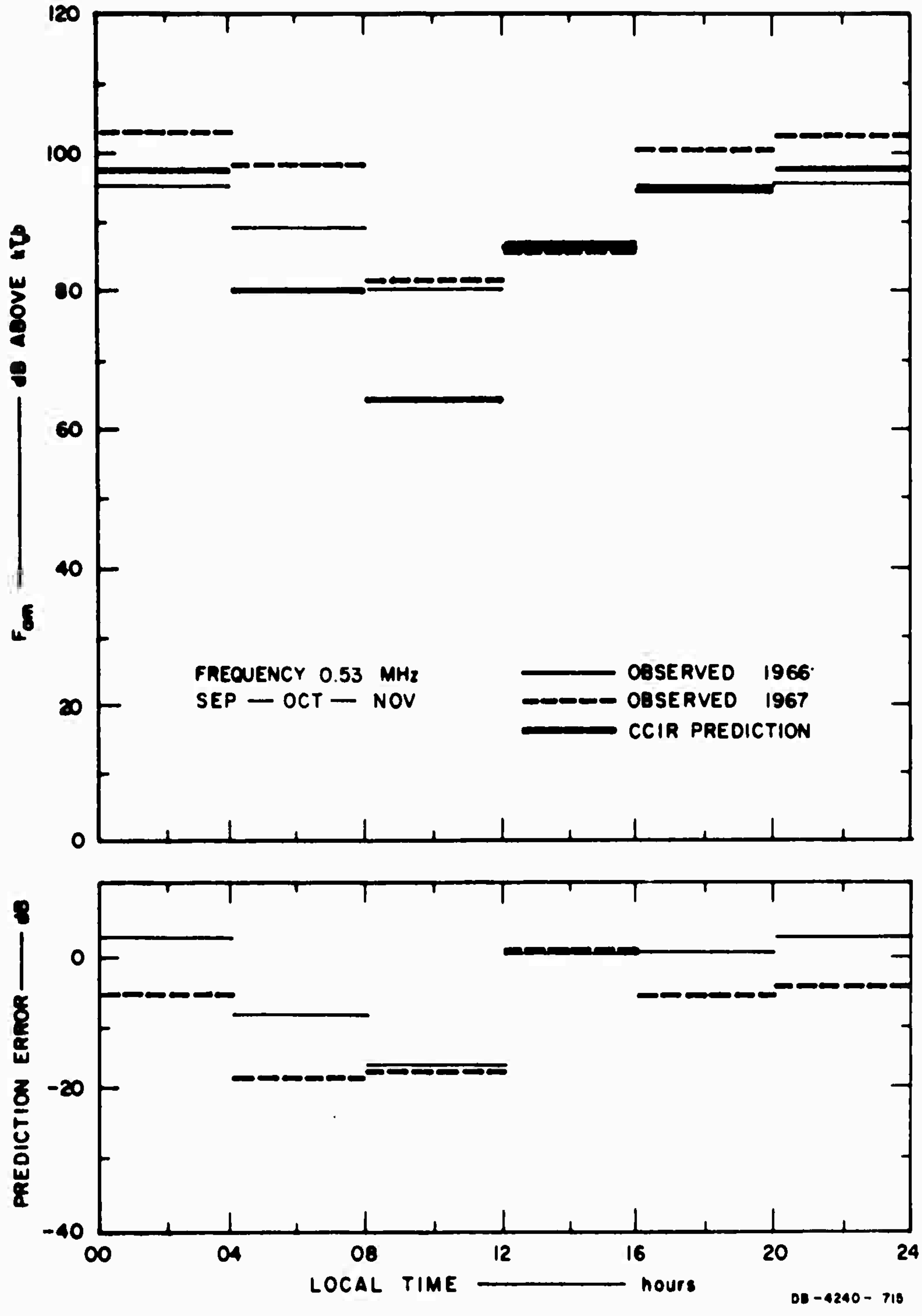

FIG. 26 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR AUTUMN 1966 AND 1967 — 0.53 MHz

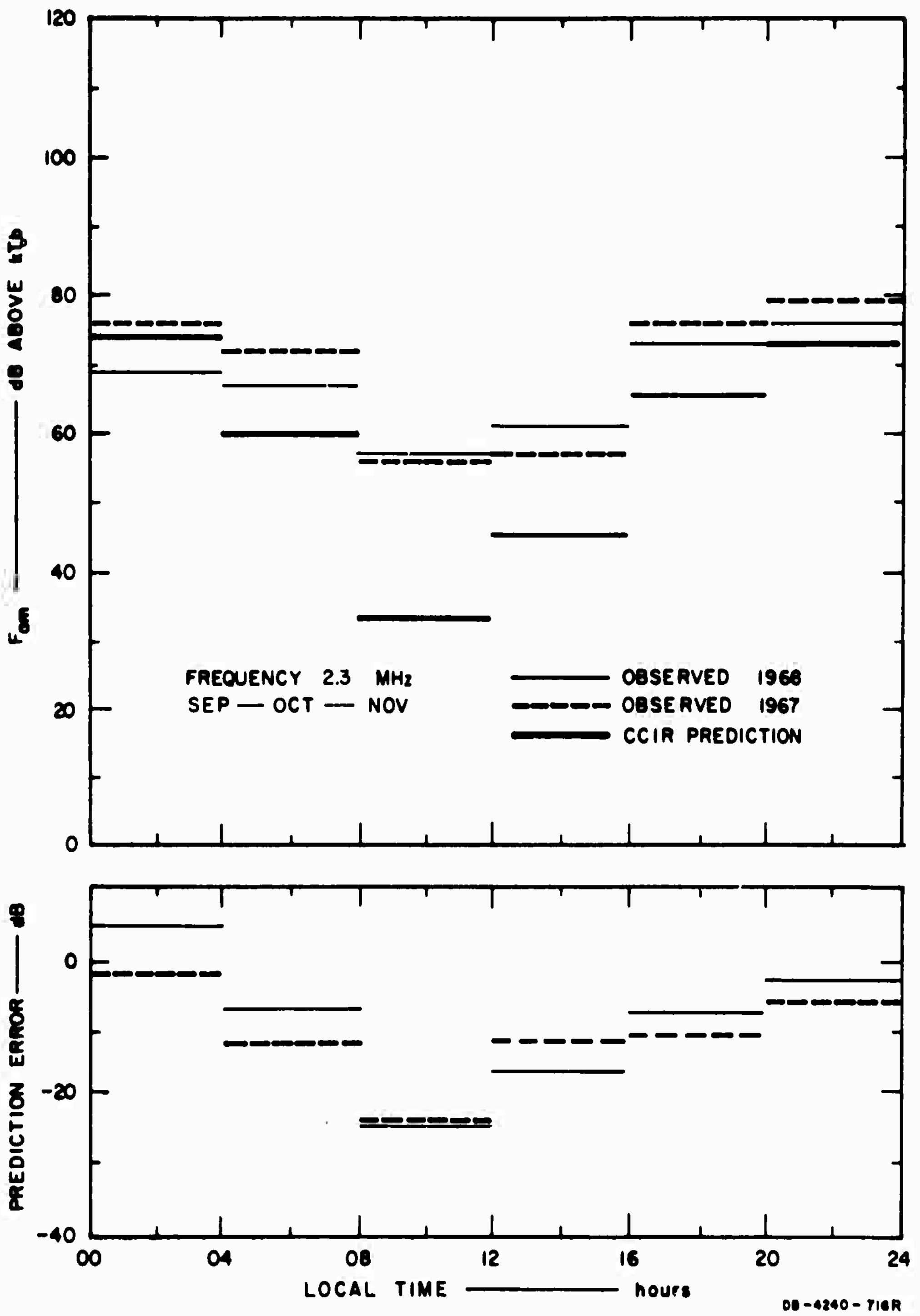

FIG. 27 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR AUTUMN 1966 AND 1967 — 2.3 MHz

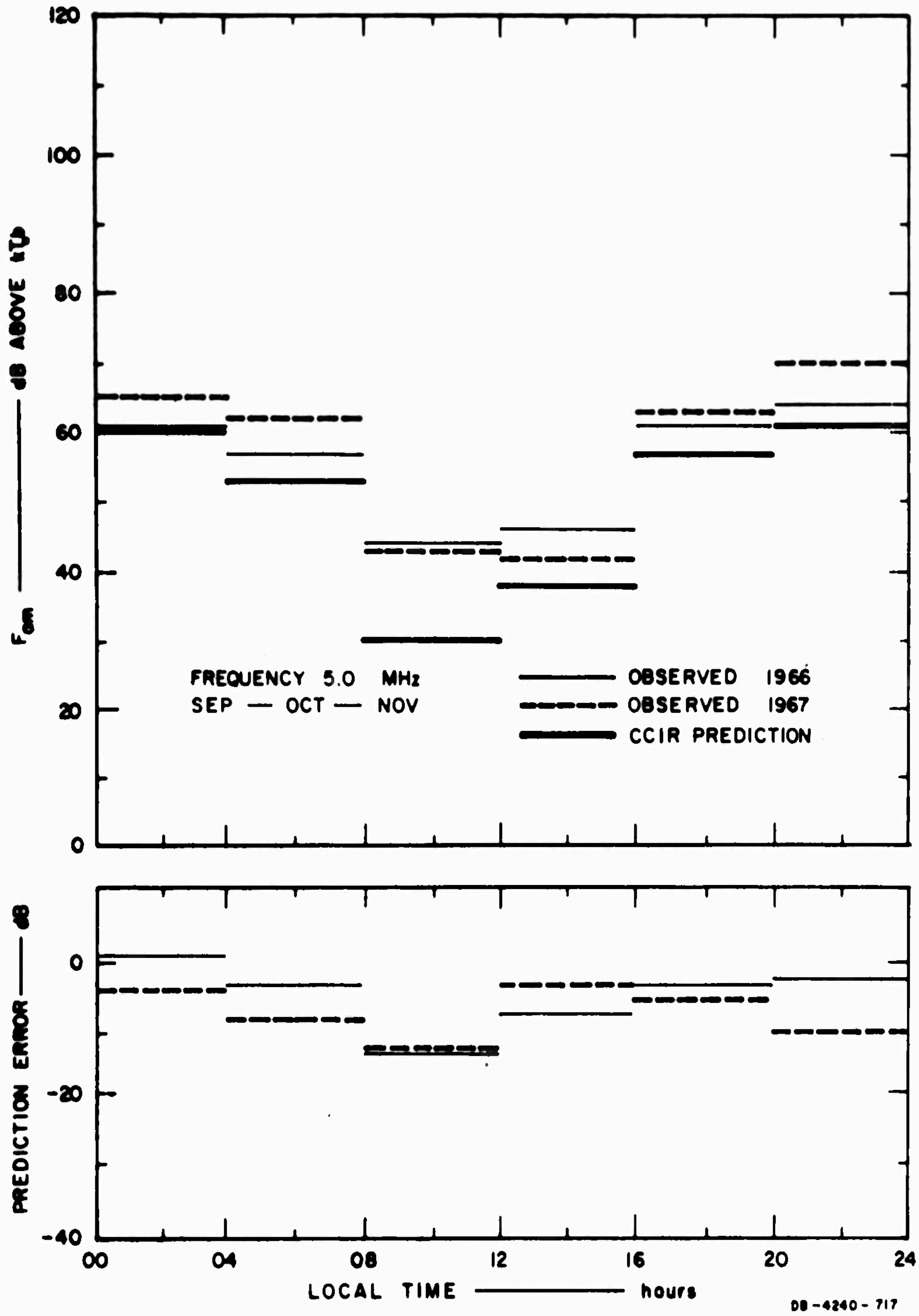

FIG. 28 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR AUTUMN 1966 AND 1967 — 5.0 MHz

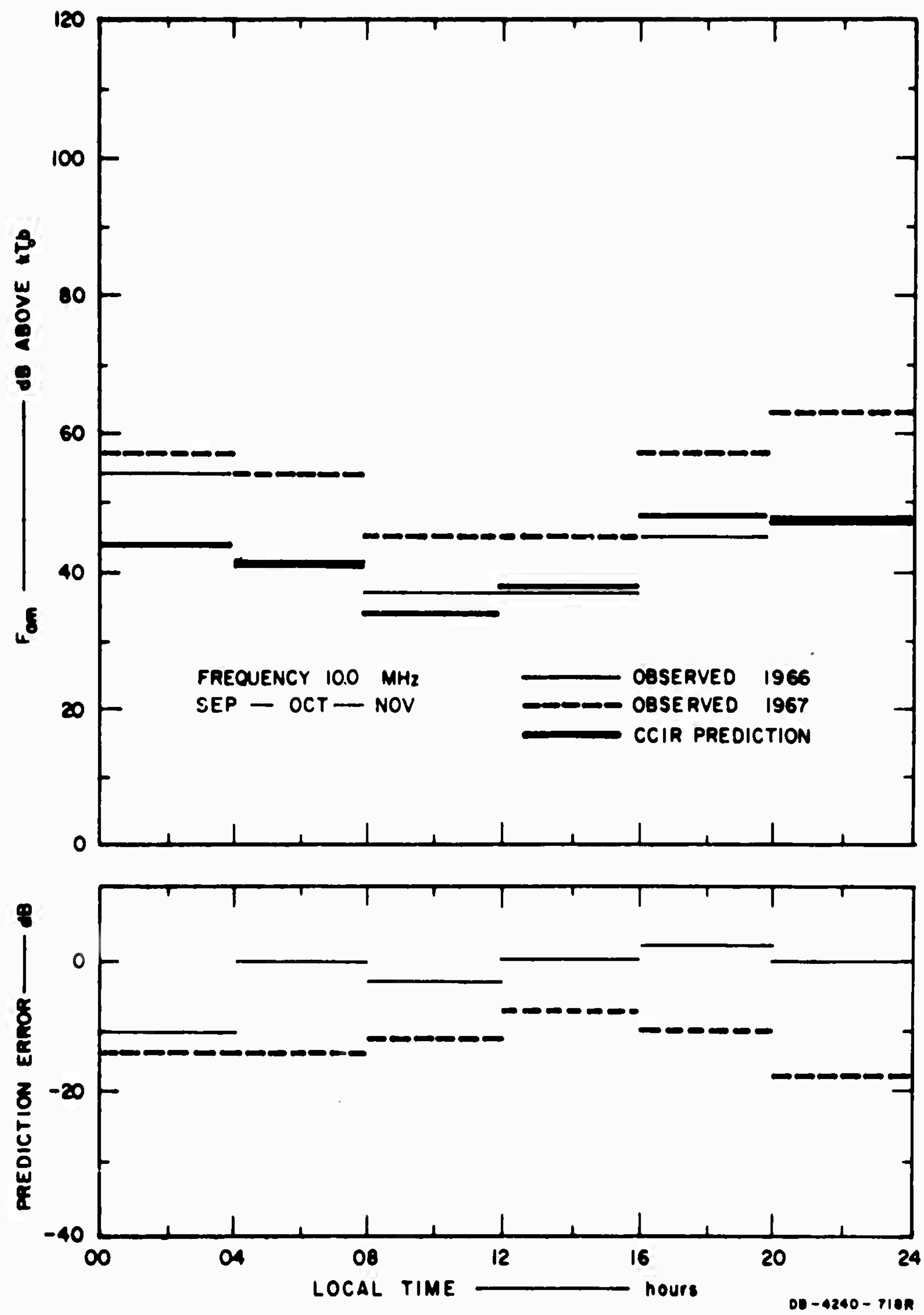

FIG. 29 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR AUTUMN 1966 AND 1967 — 10.0 MHz

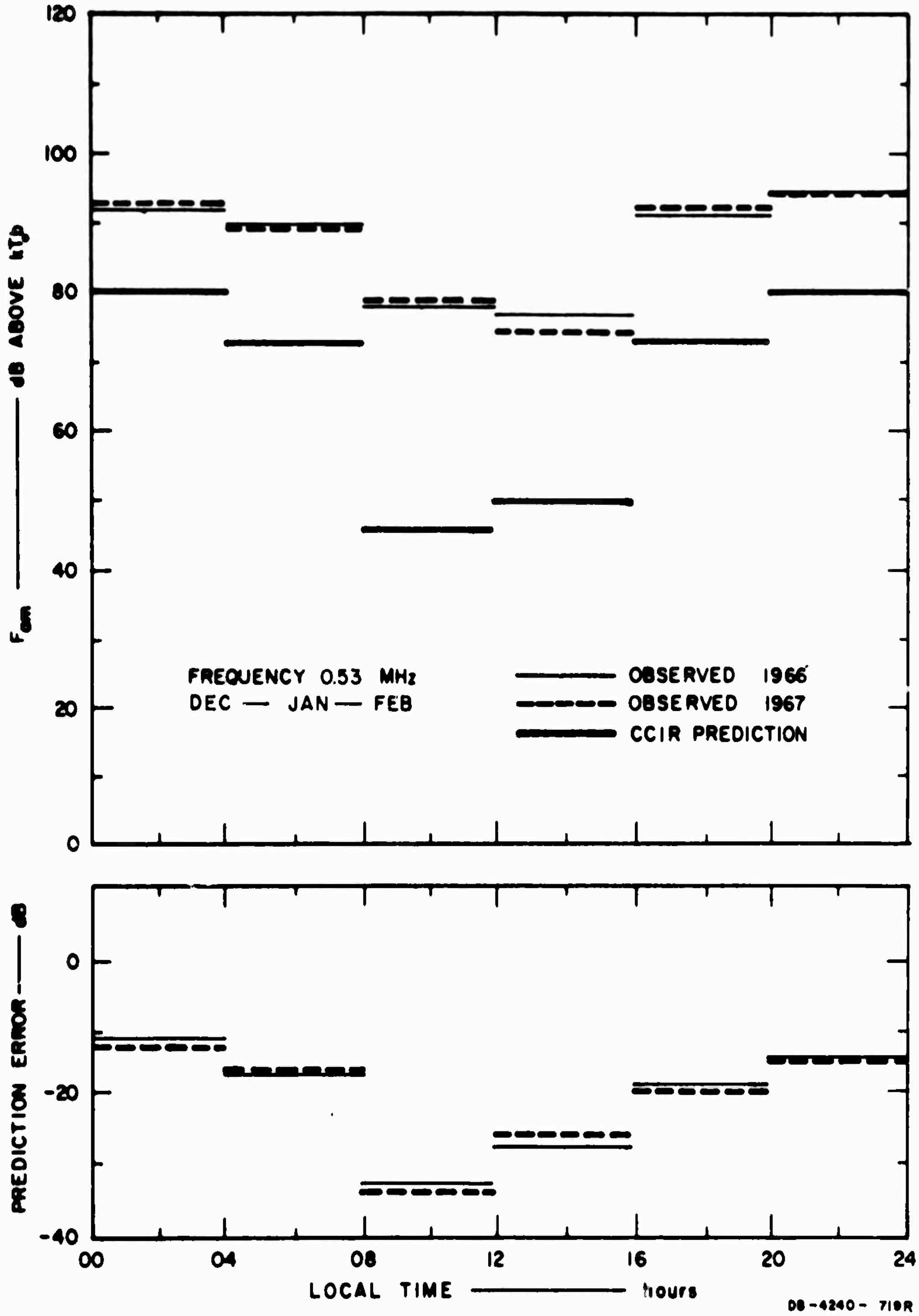

FIG. 30 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR WINTER 1966 AND 1967 — 0.53 MHz

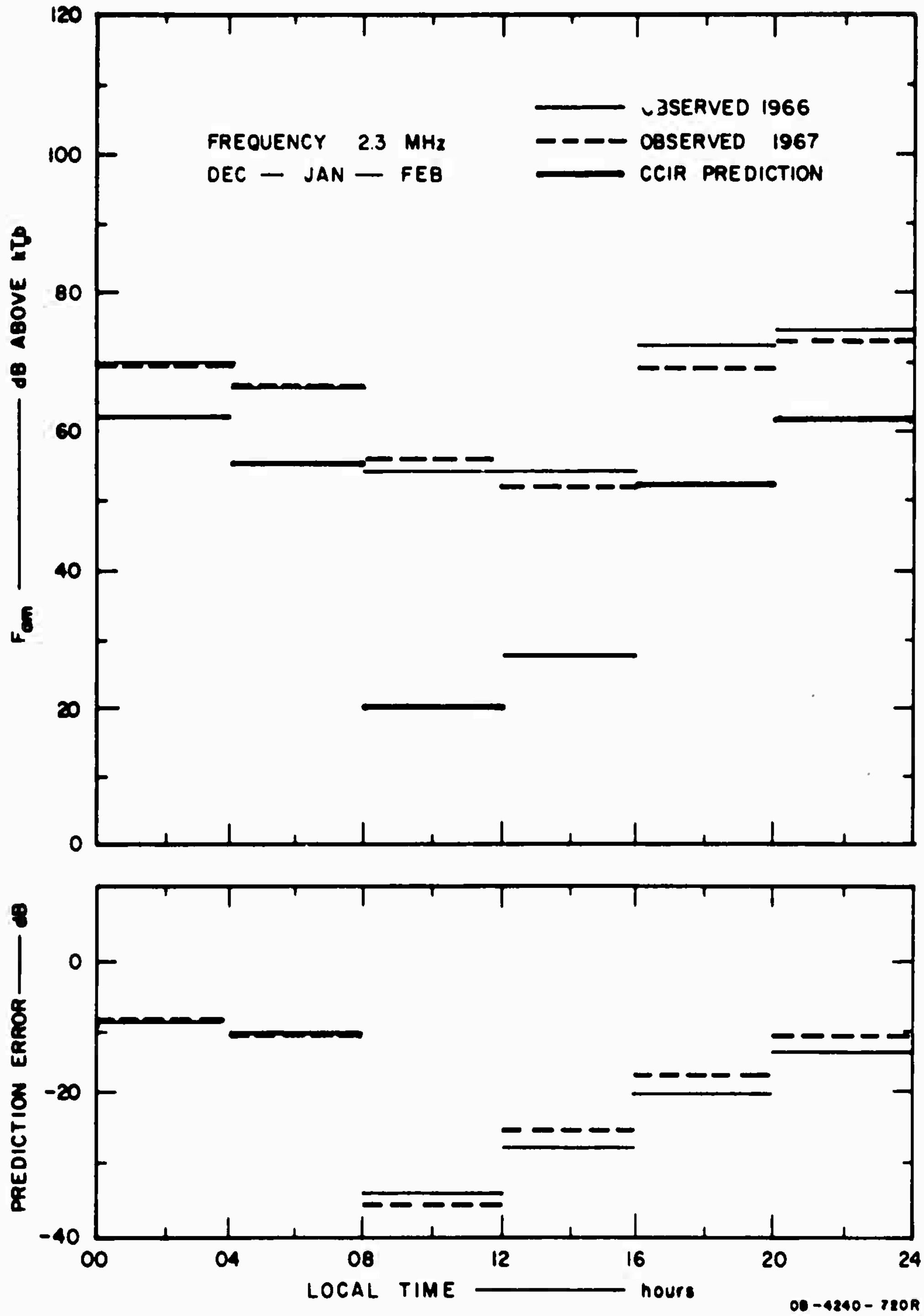

FIG. 31 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR WINTER 1966 AND 1967 — 2.3 MHz

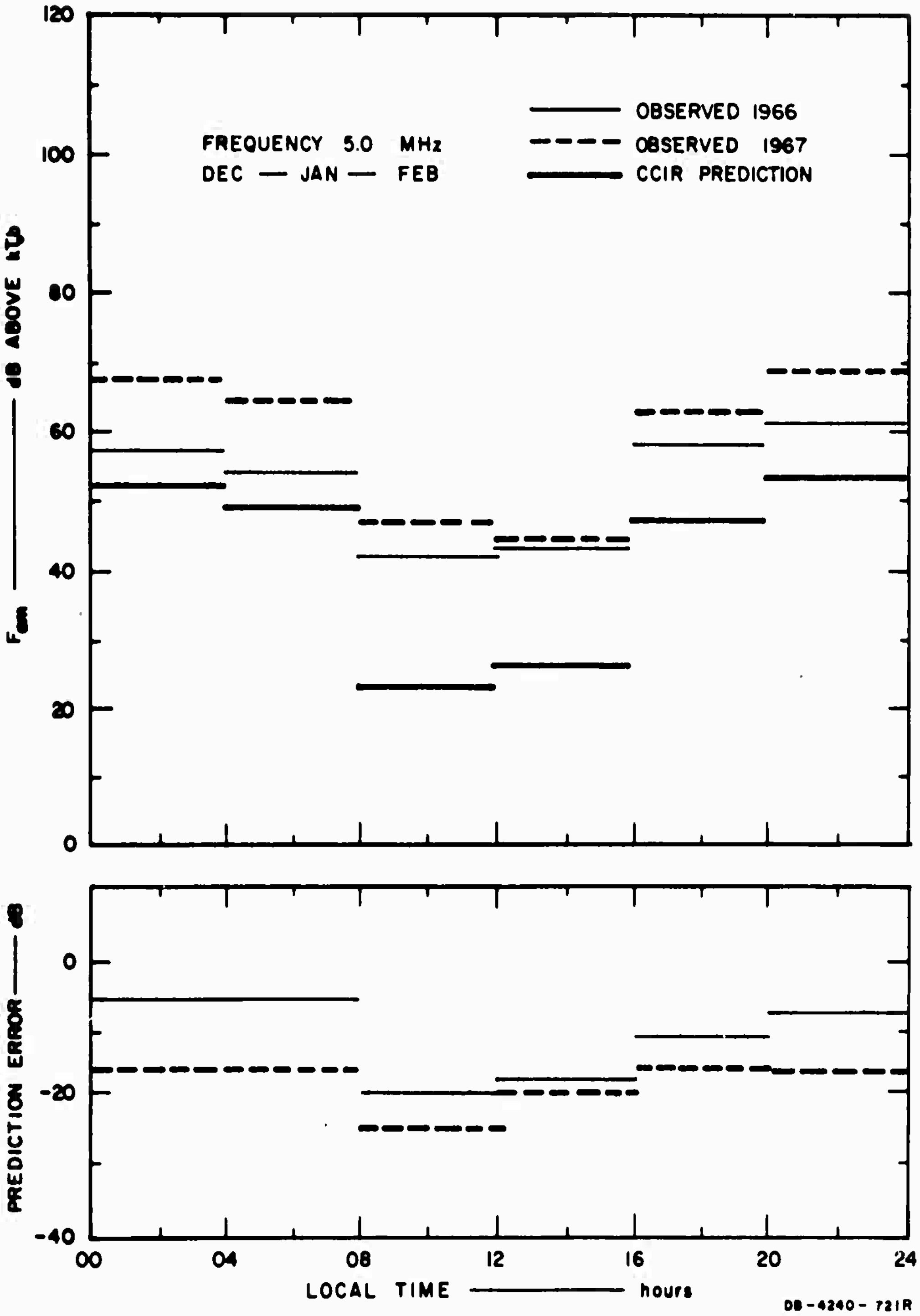

FIG. 32 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR WINTER 1966 AND 1967 — 5.0 MHz

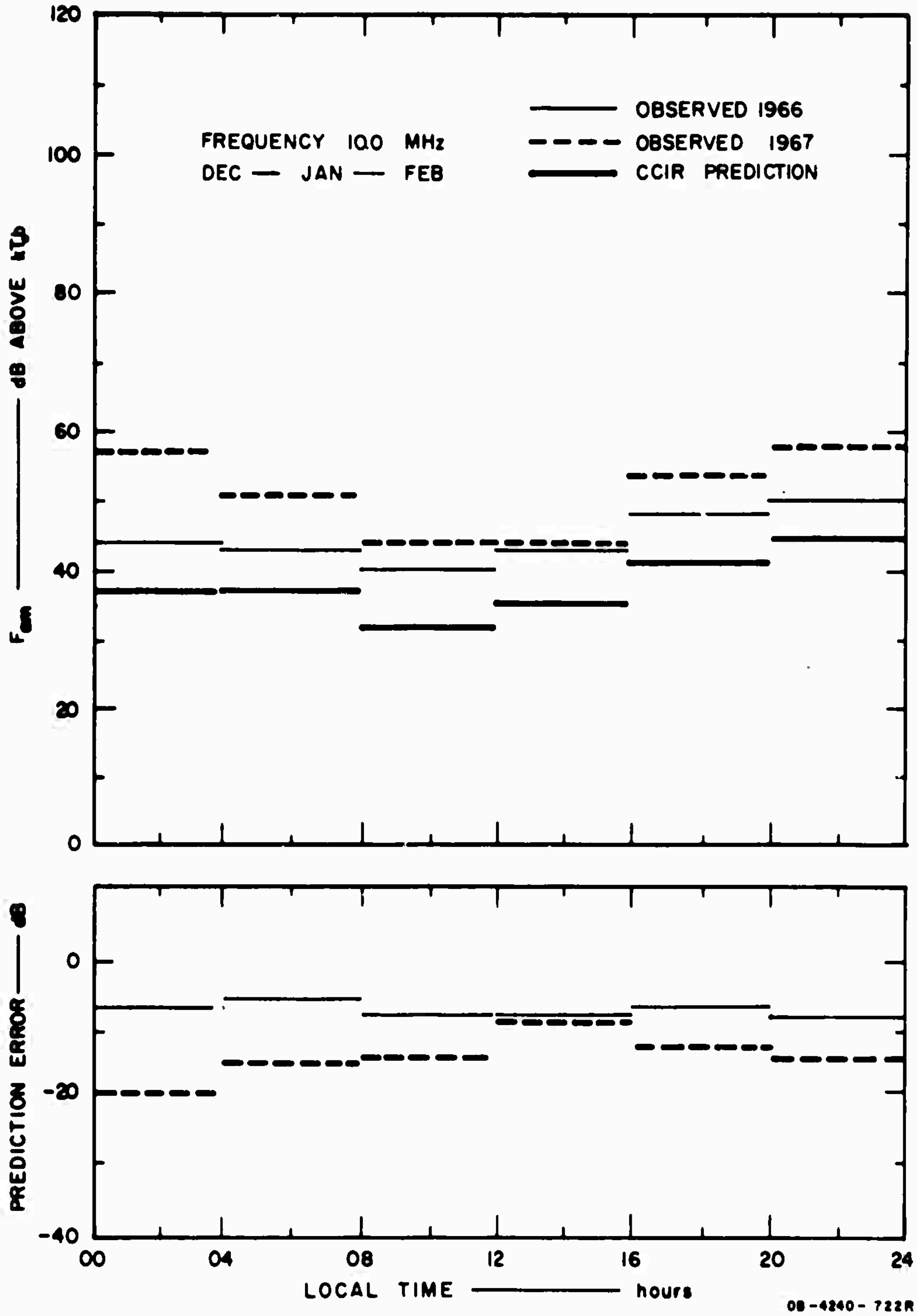

FIG. 33 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR WINTER 1966 AND 1967 — 10.0 MHz

The maximum differences between predicted and observed noise were found at the lower frequencies in the quiet season in December-January-February 1967 (see Figs. 30 and 31), the predicted values for 0.53-MHz and 2.3-MHz noise in time block 0800-1200 being lower than the observed noise by more than 30 dB. It should be observed that for this season and time block, the predicted values of atmospheric noise are substantially smaller than the expected man-made noise. If the expected man-made noise is compared with measured noise, the prediction is still too low but only by about 15 dB.

It has been observed that the largest discrepancy between measured and predicted noise power often occurs during the middle of the day. It has also been noticed that the largest spread of measured data about the median occurs near noon in many cases. An indication of the correlation between prediction error and data spread is given in Fig. 34. The average prediction error for each four-hour time block was obtained by averaging the errors shown in Figs. 18-33. The data spread was obtained by calculating four-hour time-block values from the hourly data shown in Fig. 9. It can be seen that for 0.53, 2.3, and 10.0 MHz, there is a definite correlation between the shapes of the prediction-error and data-spread curves. For 5.0 MHz, there appears to be a positive correlation from about 0800 until midnight but a lack of correlation in the early morning hours.

A comparison has also been made between predicted and measured values of noise based upon variation of noise with frequency rather than with time of day. It has been found that the agreement is better during evening, night, and early morning than during the midday hours when the observed values are lowest. Figures 35 and 36 illustrate this comparison. For the nighttime block (2000-2400) the discrepancy is relatively constant with frequency, but for the daytime (1200-1600) the error is considerably less at 5.0 and 10.0 MHz than at the lower frequencies. The minimum in noise predicted at approximately 5.0 MHz is not observed, but the observed noise continues to decrease to the highest frequency of measurement (10 MHz).

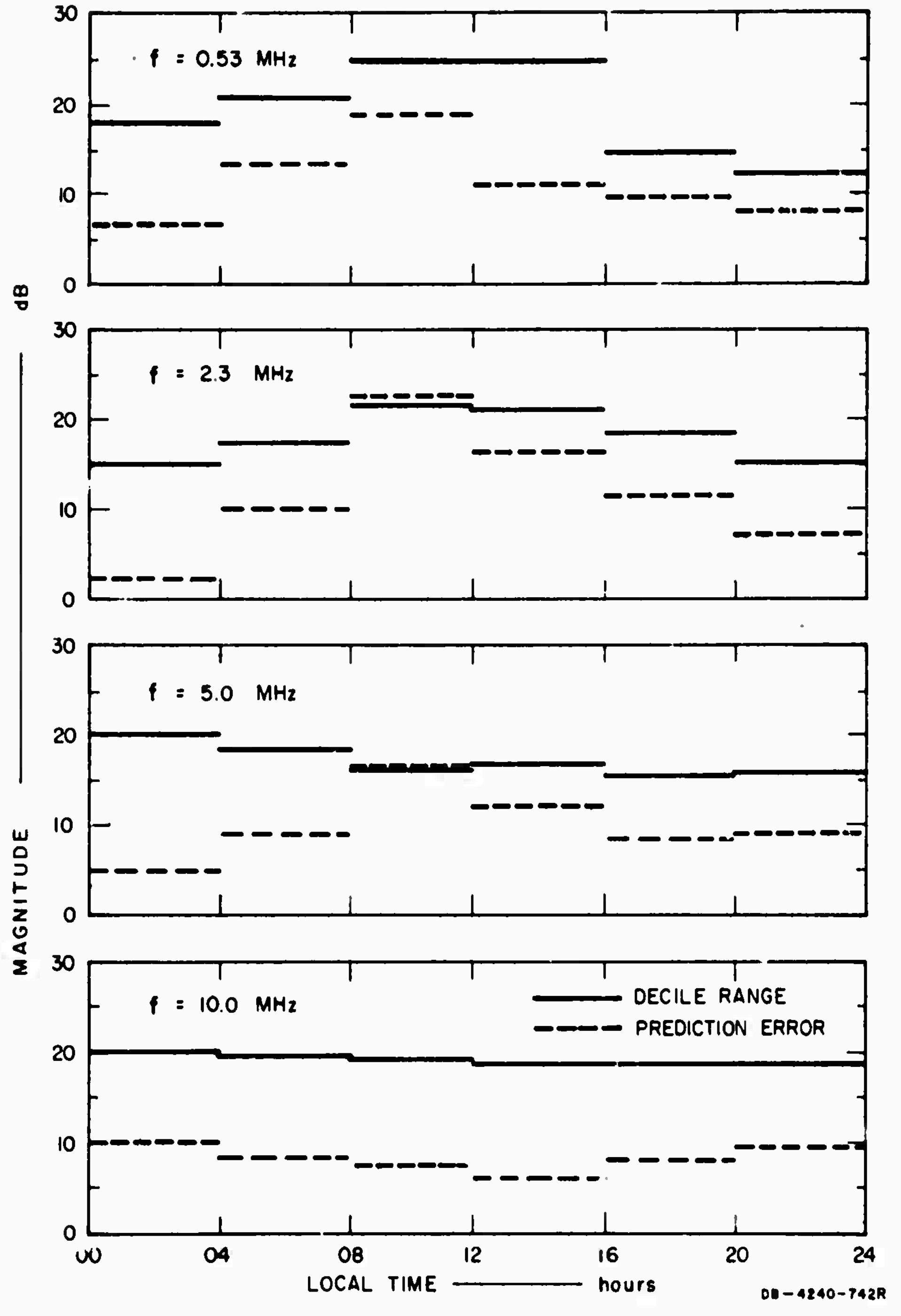

FIG. 34 COMPARISON OF PREDICTION ERROR AND NOISE-DATA SPREAD

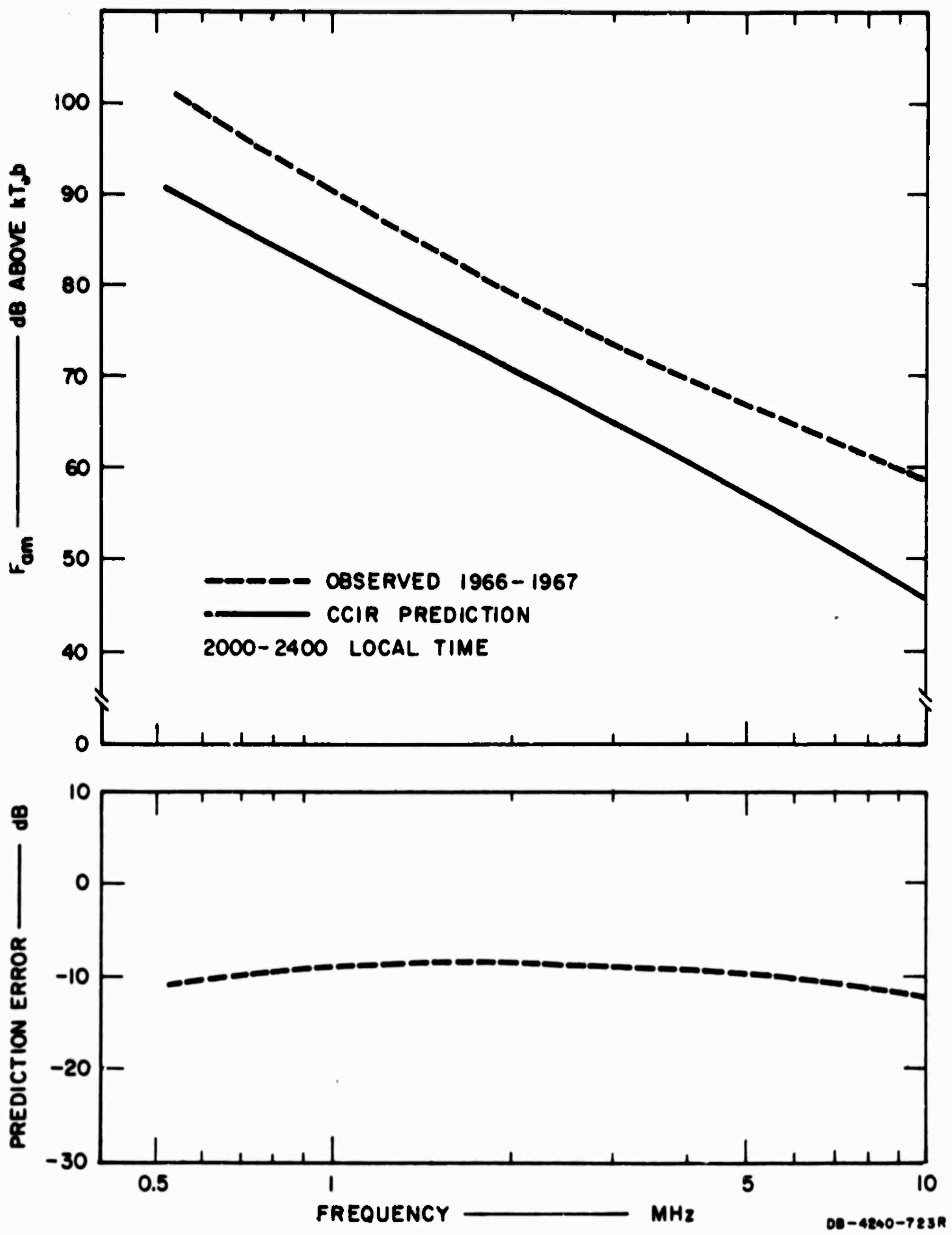

FIG. 35 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR A NIGHTTIME BLOCK (2000-2400)

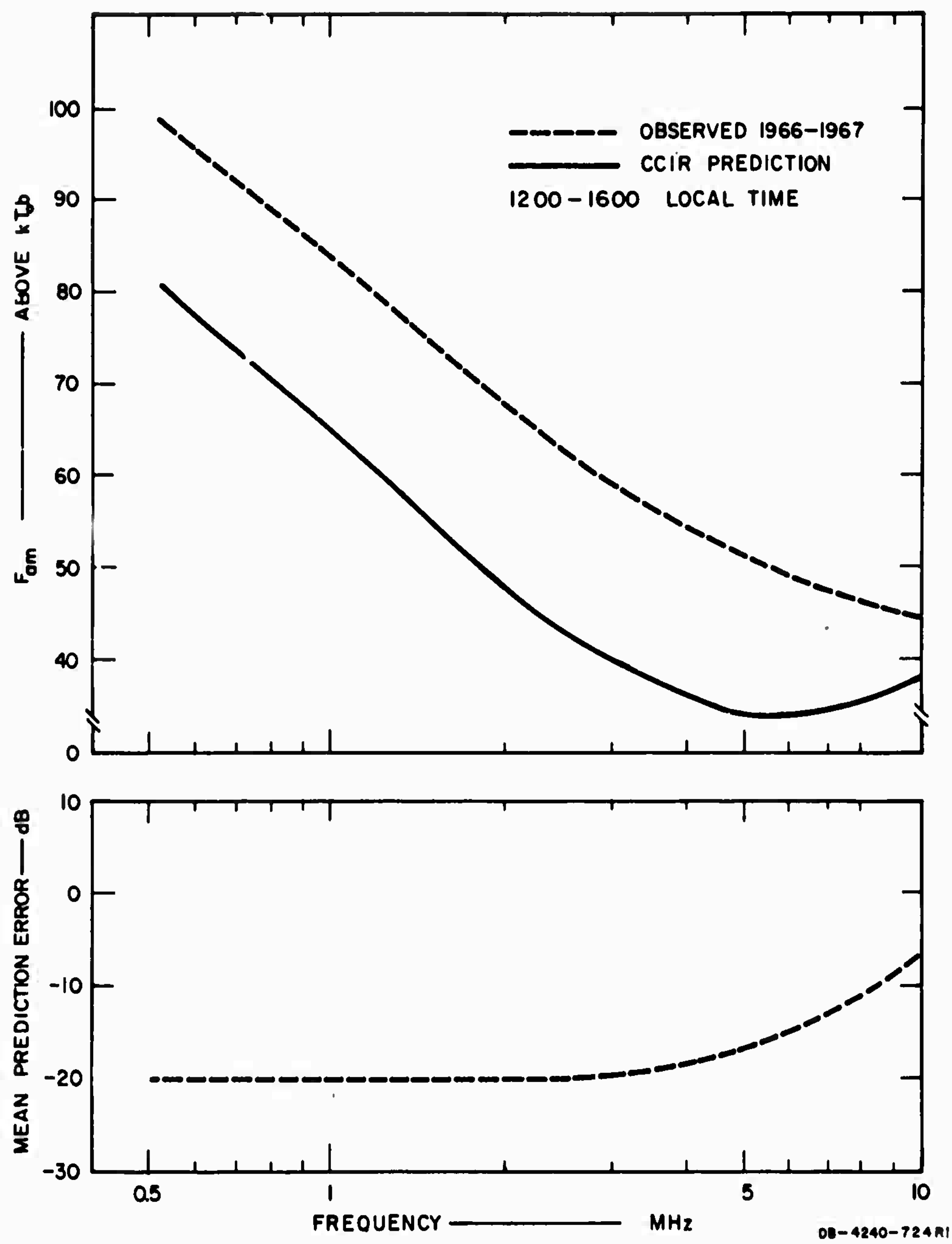

FIG. 36 COMPARISON OF OBSERVED AND CCIR-PREDICTED NOISE POWER, F_{am}, FOR A DAYTIME BLOCK (1200-1600)

C. Determination of Correction Factor to Noise Predictions

Analysis of the relatively limited amount of atmospheric noise data indicates clearly that the observed noise is almost always greater than the predicted noise. Although a good correlation of magnitude of the discrepancy with time block or season has not been found, the discrepancy is generally larger between 0800 and 1600 than at other times of day and during winter than in other seasons. A significant improvement in the prediction accuracy* can be made by: (1) for winter, adding 14 dB to all predictions, and (2) for the other seasons, adding 14 dB to predictions for the 0800-1200 and 1200-1800 time blocks and 7 dB to the predictions for other time blocks. The principal effect of adding these corrections is to eliminate the negative bias of the uncorrected predictions.

A better correction of the predicted noise values can be obtained by using the correction factor curves of Figs. 37 through 40, which have been obtained by comparison between predicted and measured noise for 1966 and 1967. By adding these corrections to the predictions, one may obtain a corrected prediction for any time block, any frequency, and any season. It must be remembered, however, that corrections obtained in this way do not take into account any long-term (for example, sunspot cycle) variation of the noise. In most cases, though, it is expected that a more accurate prediction can be made in this way than by using the simple correction suggested in the previous paragraph.

An alternate method of generating correction factors for the predictions has been suggested by Mr. W. Q. Crichlow. In this method, pseudo-experimental values of the noise grade (noise level at 1 MHz) obtained by interpolation between measured values at 0.53 and 2.3 MHz, are compared with predictions scaled from the CCIR contour maps.[1] Corrections at 1 MHz for all ~~all~~ time blocks and seasons are then calculated. Finally,

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* Where predicted man-made noise exceeds predicted atmospheric noise the former should be considered the predicted value.

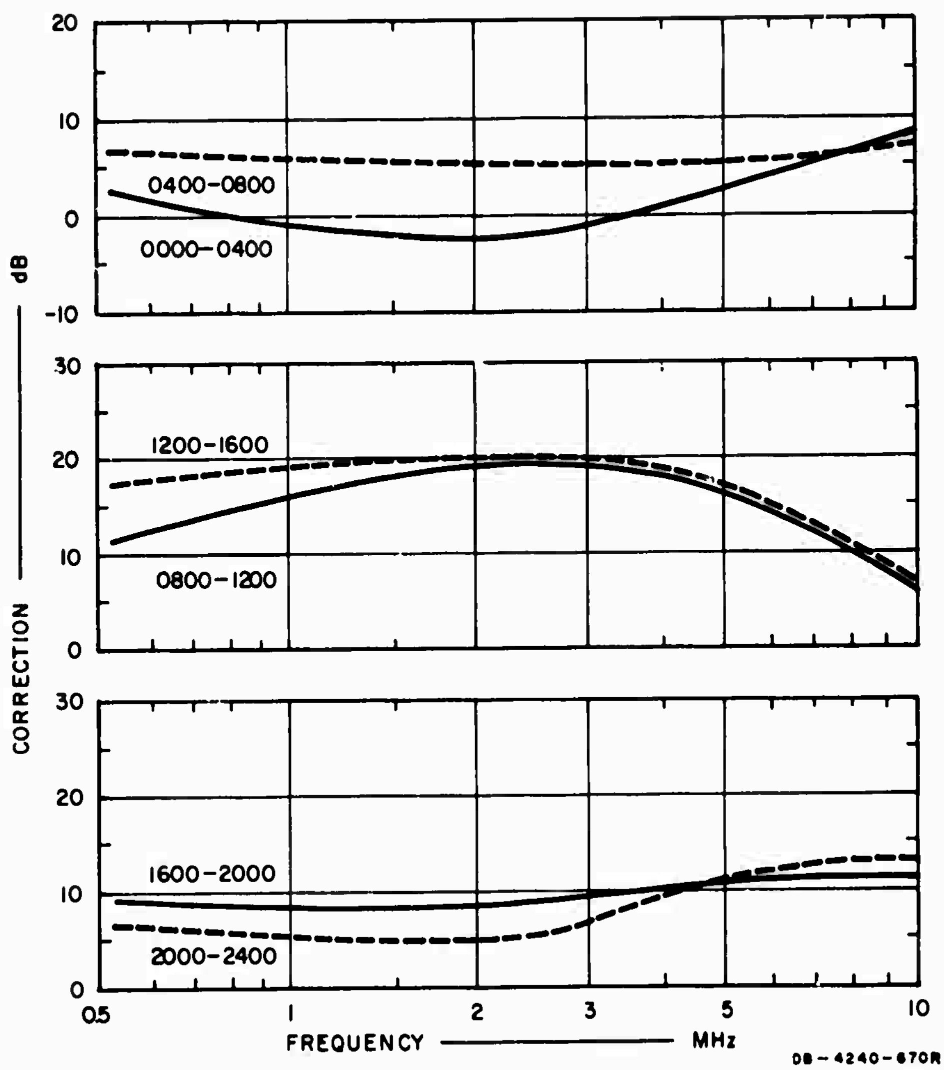

FIG. 37 CORRECTION OF THE CCIR-PREDICTED NOISE POWER, F_{am}, AT MF AND HF FOR SPRING 1966 AND 1967

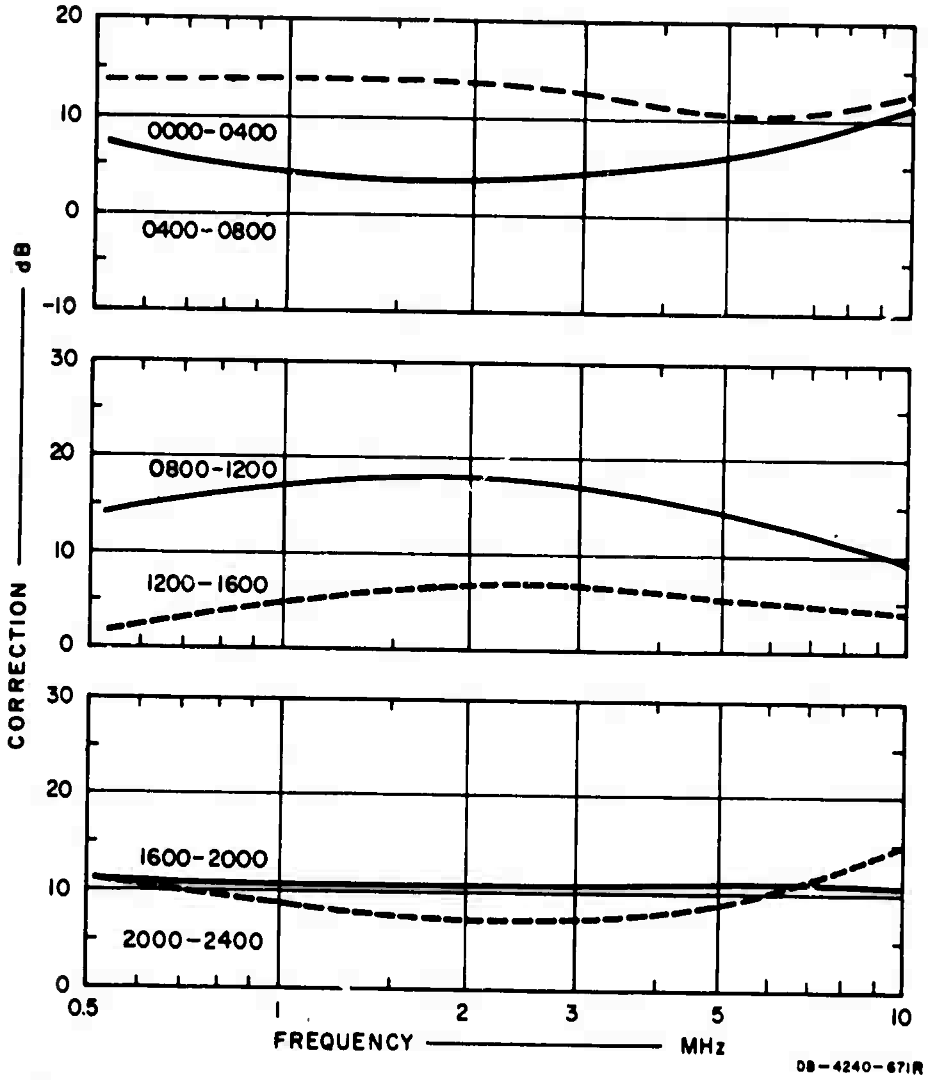

FIG. 38 CORRECTION OF THE CCIR-PREDICTED NOISE POWER, F_{am}, AT MF AND HF FOR SUMMER 1966 AND 1967

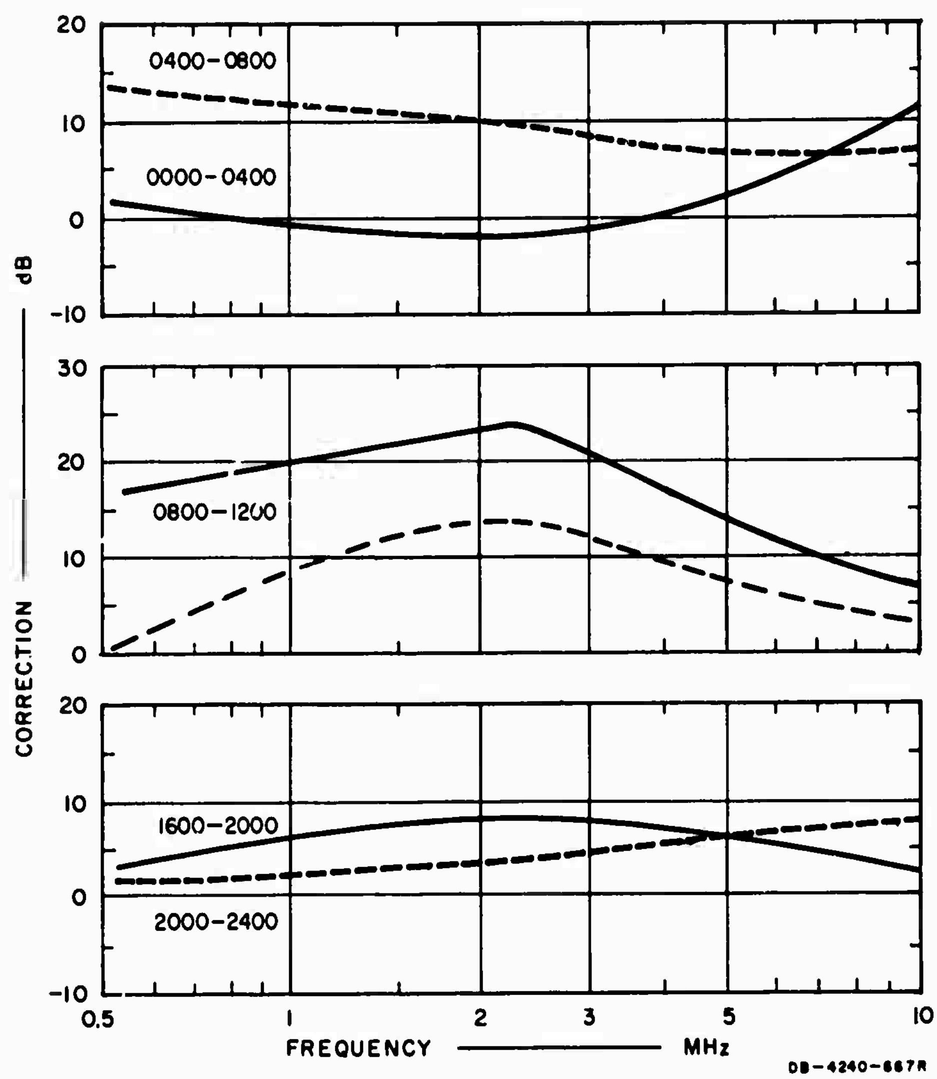

FIG. 39 CORRECTION OF THE CCIR-PREDICTED NOISE POWER, F_{am}, AT MF AND HF FOR AUTUMN 1966 AND 1967

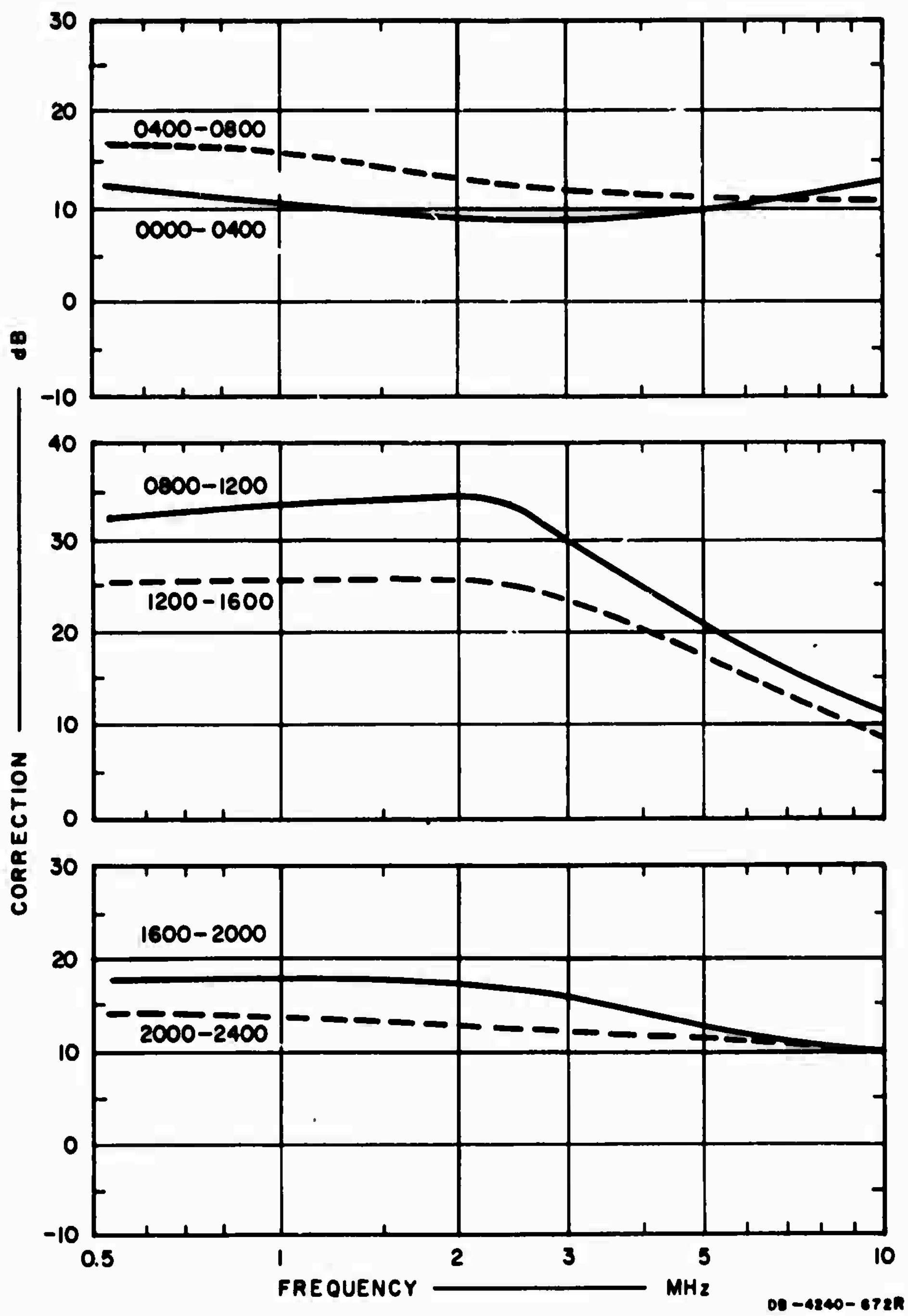

FIG. 40 CORRECTION OF THE CCIR-PREDICTED NOISE POWER, F_{am}, AT MF AND HF FOR WINTER 1966 AND 1967

the series B curves are used with the corrected noise grades to get corrected predictions at any other frequency of interest.

In practice the pseudo-experimental noise grades were obtained as follows. First the averages of the month-hour medians for all the values (12) in a particular time block and season were calculated for 0.53 and 2.3 MHz. Then the noise grade was calculated by linear interpolation between the average values for the two frequencies. In effect, the average values of noise power for 0.53 and 2.3 MHz were plotted on a series B graph, a straight line was drawn between these points, and the noise power at the 1 MHz crossing of this line was read.

A comparison of the pseudo-experimental noise grade with expected values from the CCIR maps showed that the observed noise was almost always greater than that predicted and that the discrepancy was significantly larger during the midday time blocks (0800-1200 and 1200-1600) than at other times. The median noise for seven seasonal values in these two time blocks was calculated on the basis of arbitrary rules. First, the basic data were obtained by taking the difference between measured and expected noise for all 14 cases even though in some cases the expected atmospheric noise was less than the anticipated man-made noise (see series B figures in Ref. 1). The median of these differences was -17 dB (expected was less than measured). Second, the difference was calculated only if the expected atmospheric noise was greater than the anticipated man-made noise. The average of the 7 values obtained in this way was -13 dB. Third, the difference was calculated for all 14 cases, using the larger of the expected atmospheric or man-made noise for the predicted value. The median of these differences was -14 dB. From these considerations it would seem that a correction of approximately 14 dB is realistic for hours between 0800 and 1600. For other times of day, the median of 28 values of the difference between expected and measured atmospheric noise was -8 dB. The expected atmospheric noise is at least 10 dB greater than the man-made noise during this period.

The median differences between experimental and expected noise grade were applied as corrections* to the expected noise grade, and a new set of noise grades was obtained. Then the "corrected" estimates of noise at 3 and 10 MHz were read from the series B curves. A comparison of corrected estimates with measured values of noise at 5 and 10 MHz showed that these predictions were too low, in spite of the correction that had been made at 1 MHz. The median of the differences between corrected estimates and measured values was 4 dB at 5 MHz and 6 dB at 10 MHz. At neither frequency did the discrepancy show any significant correlation with season or time block.

The series B curves show variation of noise with frequency and are parametric in magnitude of noise (adjacent curves are spaced 10 dB apart at 1 MHz). The curves are approximately parallel between 0.5 and 2.5 MHz but are bunched at higher frequencies, the extent of bunching depending on time block and season. An effect of bunching is to decrease substantially the magnitude of a correction for 5 or 10 MHz compared with the correction at 1 MHz (the noise grade). For example, the 14-dB noise-grade correction for the 1200-1600 time block in autumn is reduced to 4.5 dB at 5 MHz and 2.5 dB at 10 MHz. A less extreme case is illustrated by the 0000-0004 time block in summer, where an 8-dB noise-grade correction is reduced to 4 dB at 5 MHz and 3 dB at 10 MHz. The median of the corrections calculated from the series B curves was 4.5 dB at 5 MHz and 3 dB at 10 MHz (these calculations take into account the degree of bunching at each time block and season, as well as the noise-grade correction at each time block). Since the "uncorrected" predictions were too low by about 11 and 9 dB at 5 and 10 MHz, respectively, corrections of 3 or 4 dB are much too small to bring measured and predicted values into agreement at the higher frequencies. Therefore, the method of correcting the noise-grade prediction based on measurements in Thailand and using the series B curves to obtain predictions at 5 and 10 MHz does not appear very satisfactory.

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* A correction of 14 dB was added in the 0800-1200 and 1200-1600 time blocks; a correction of 8 dB was added in all other time blocks.

D. Effect of Local Storms on Measured Noise Power

The atmospheric noise recorded by the ARN-3 equipment arises from both local and distant thunderstorms. Since the number of lightning flashes registered by a lightning flash counter, is a good measure of local thundery activity, it is interesting to compare lightning flash counts per hour with noise power (F_a) measured for the same hour in order to study the effect of local storms on measured noise power. The lightning flash analyzer[3] and a Prentice (ERA) counter* were operated at Laem Chabang during part of the period (March 1966 - November 1967) when ARN-3 measurements were made. Four-day periods that included considerable thunderstorm activity were analyzed since both a significant number of data points and a substantial range of lightning flash counts can be obtained in a period of this length.

The results of an analysis of data from the CCIR (1-volt threshold) portion of the lightning flash analyzer are illustrated by Fig. 41, which shows noise-power variation as a function of number of lightning flash counts per hour for noise at four frequencies. Each plotted point represents the noise measurement and the flash count for a particular hour during the four-day period (10 through 13 November 1966). In order to reduce the effect of normal diurnal variation of noise power, the difference between measured noise for a particular hour and day and the monthly median for that hour is plotted. These scatter plots indicate a definite increase in noise power with increasing lightning flash count at 0.53 MHz, a small increase at 2.3 MHz and 5 MHz, and no significant upward trend at 10 MHz. The data are summarized in Fig. 42a, in which the data of Fig. 41 are replotted to show the average noise power (relative to monthly median data) as a function of lightning flash activity.† Notice that the

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* This counter[17] was loaned by Professor S. A. Prentice, University of Queensland, St. Lucia, Brisbane, Queensland, Australia.

† For example, the point on the 0.53 MHz curve corresponding to the index A was obtained by averaging the ordinate values of the 30 points in the count interval of 11-25 in the top curve of Fig. 41.

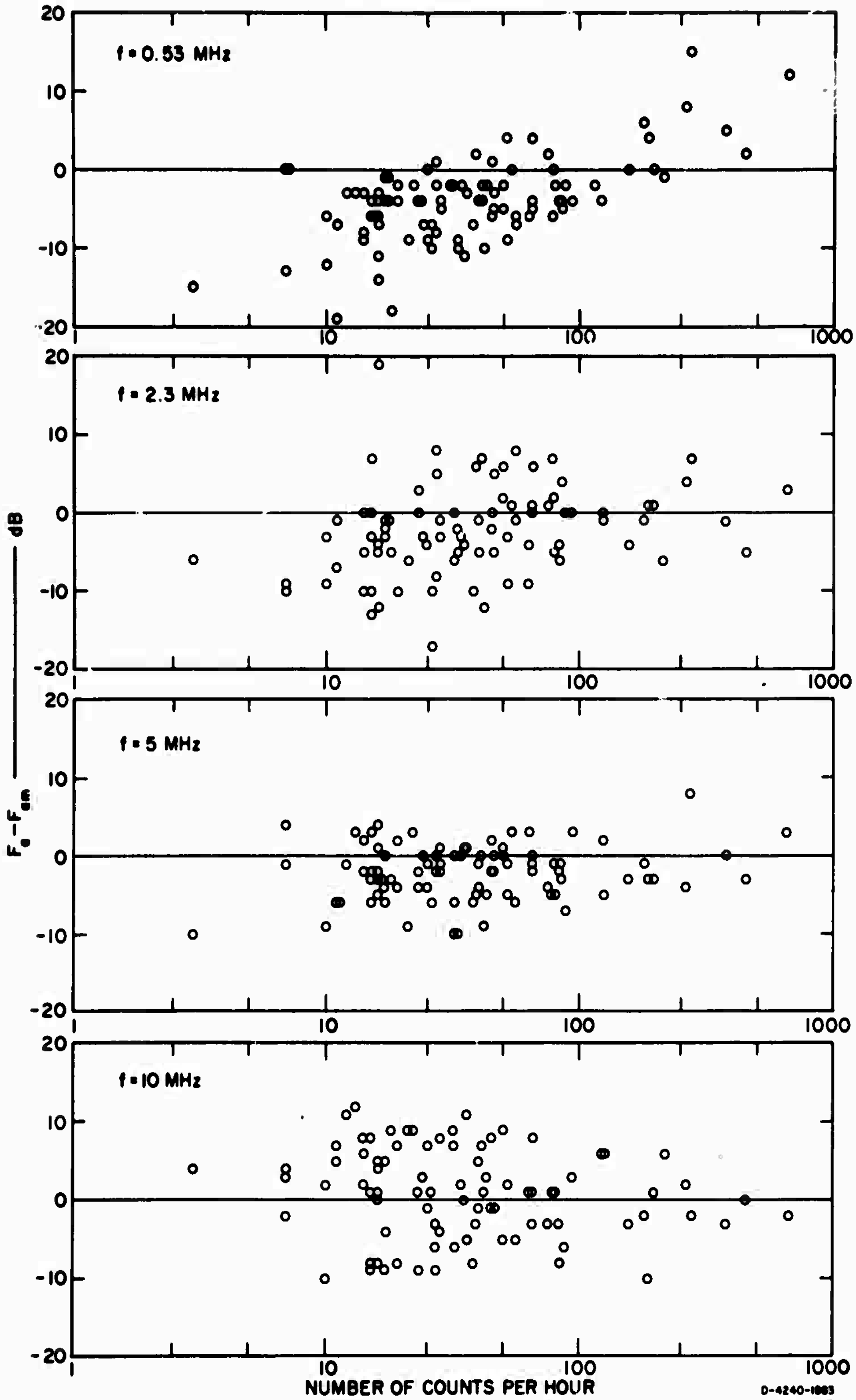
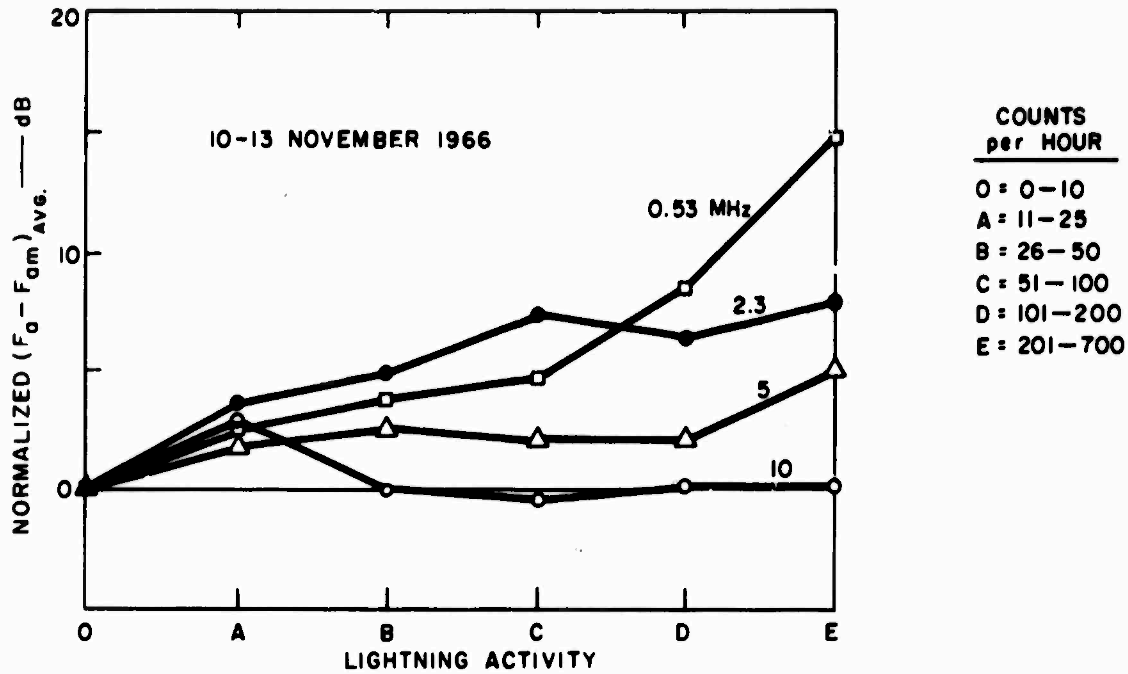
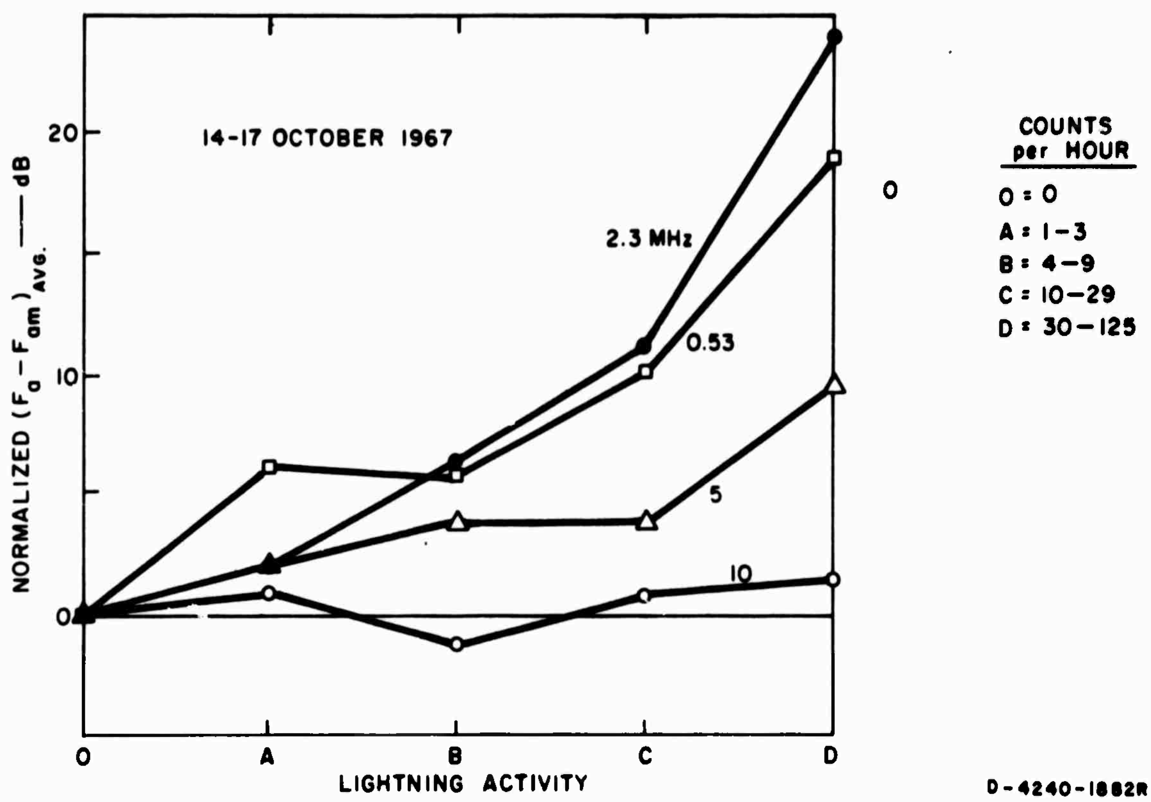


FIG. 41 VARIATION OF NOISE POWER WITH LIGHTNING FLASH COUNT (1-Volt CCIR Counter)



(a) CCIR COUNTER, 1-VOLT THRESHOLD



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(b) ERA COUNTER, 3-VOLT THRESHOLD

FIG. 42 NORMALIZED NOISE POWER AS FUNCTION OF LIGHTNING ACTIVITY

curves have been normalized to 0 dB at the smallest index of flash activity (0-10 counts per hour) to emphasize the trend of the data.

Measurements taken with the ERA counter during a similar four-day period (14 through 17 October 1967) are summarized in Fig. 42b where again the average noise power relative to monthly median data is plotted against lightning flash activity. In general, Figs. 42a and 42b are quite similar, showing considerably greater dependence of noise power on lightning activity at 0.53 and 2.3 MHz than at the higher frequencies. The ERA counter data, however, show a larger change in noise level between the conditions of few and many counts than do the CCIR data. The lightning data were collected during different periods of time and the severity of thunderstorms are probably not equal; in fact, noise power and lightning flash data indicate that October 1967 was stormier than November 1966. Furthermore, some of the difference is due to differences between the two types of counters.[18] It should be noted that the ERA counter is a better indicator of local storms because it responds predominantly to the electrostatic components of the electric field due to the lightning discharge, which dies out at a rate proportional to the cube of distance from the discharge. The CCIR counter responds to the radiation field, whose magnitude varies inversely with distance and, consequently, has a larger and less well-defined range. Thus a large change in ERA counts indicates a significant change in local thunderstorm activity, which is reflected in the noise level measured by the ARN-3 equipment. A large increase in CCIR counts, on the other hand, may be due partly to thunderstorms so far away that the noise energy they contribute to the total measured by the ARN-3 is not appreciable. The difference between Figs. 42a and 42b can be principally ascribed to the difference between the two types of counter in range and the precision of its definition. However, there are other complicating factors. It should be recalled that the noise power generated by a lightning flash decreases rapidly as frequency increases, and so also--in consequence--does the dominance of lightning noise over other forms of interference. In addition, the larger impulses from thunderstorms 100 km or more away operate the CCIR instrument but do not affect the ERA counter; for these storms

at intermediate distances the noise contribution at MF and HF from ionospherically reflected rays (with its complicated temporal dependency) can be significant.

A comprehensive study of lightning flash (CCIR counter) and noise power (ARN-2) data for Singapore has been reported by Horner.[19] His analysis indicates that noise power increases substantially with increasing flash count at all frequencies measured (13 kHz to 20 MHz). This seems to be at variance with Laem Chabang data, which show a much larger increase at 0.5 than at 2.3 and 5.0 MHz and virtually no change at 10 MHz. This discrepancy may be explained, in part, by a difference in the range of measured flash counts and noise power. Because the Singapore measurements were made at 3 volts and the Laem Chabang measurements were made at 1-volt threshold, only 20-25 percent of the Laem Chabang counts would be expected at Singapore if the storms were the same. Since the number of counts per hour for Singapore (maximum about 1100) is similar to that for the sample period at Laem Chabang (maximum about 700), one can infer that substantially more intense storms were recorded at Singapore.* Somewhat better agreement, especially at 10 MHz, can be seen if the highest counts (more than 100) in the Singapore data are excluded from the comparison. To investigate this point further, the raw data for periods including intense storms at Laem Chabang should be reexamined.

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* It should be noted that Laem Chabang noise-power data for periods of greatest flash counts are not included in Figs. 41 and 42, due to an oversight in scaling the noise chart recording. One cannot conclude that there was a significant difference in actual storm activity, at Laem Chabang and Singapore.

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IV DISCUSSION

The results of a 24-month (March 1966-February 1968) period of measurement of atmospheric radio noise at Laem Chabang, Thailand, have been analyzed to examine the variation of noise power with time of day, season, and frequency. The experimental data have been compared with expected noise as obtained by interpolation of the maps published in CCIR Report No. 322. This comparison showed that the observed noise was higher than predicted, a result that is in agreement with a conclusion reached by Ibukun in his study of noise in Nigeria.[20] The magnitudes of the discrepancies between Thailand observations and predictions are shown in Table III. Less than 10 percent of the discrepancies* were positive (measurement less than prediction) and all of these fell in the equal-to-or-less-than 5-dB range. It can be seen that the best agreement occurs in autumn (a result also reported by Ibukun)[20] and agreement is poorest

Table III

DISTRIBUTION OF DISCREPANCIES
BETWEEN OBSERVED AND PREDICTED NOISE POWER

Magnitude of Discrepancy (Δ) (dB)	Fraction of Data in Discrepancy Range (%)				
	Spring	Summer	Autumn	Winter	Average
$\Delta \leq 5$	27	35	52	12	35
$5 < \Delta \leq 10$	42	38	21	34	33
$10 < \Delta \leq 15$	19	17	17	17	17
$15 < \Delta \leq 20$	8	8	6	21	10
$20 < \Delta$	4	2	4	16	5

* A "discrepancy" is the difference between the predicted median and average of the monthly medians of F_a for a particular time block and season. Data for discrepancies at all (four) frequencies and time blocks in a season were averaged to obtain the numbers shown in Table III.

in winter, when the predicted noise is quite low and frequently less than the expected man-made noise. The average over all seasons and all time blocks shows that the discrepancy is no more than 15 dB for 85 percent of the cases and is more than 20 dB in only 5 percent of the cases. Ibukun reported that 90 percent of the discrepancies were no greater than 10 dB and that none exceeded 20 dB. The agreement between the Thailand and Nigeria results seems reasonably good, when one considers that the sets of measurement frequencies were not identical (0.53, 2.3, 5.0 and 10.0 MHz in Thailand and 0.051, 0.113, 0.545, 2.5, 10.0 and 20.0 MHz in Nigeria).

A brief comparison has also been made between the noise measured at Laem Chabang and predictions generated from a model recently developed at Stanford Research Institute.[21] For a 10-MHz noise in July 1966 the prediction differed from month-hour medians of the observations by 3 dB or less for about half the time. Although this comparison was too short to permit generalization, it appears that the model may give predictions of noise that are more accurate than the contour maps of Ref. 1. The model and the July 1966 comparison results are described in more detail in Appendix A.

An important question is whether the conclusions drawn from measurements of noise at Laem Chabang can be applied to other parts of Thailand. Two factors must be considered. First, can the corrections to the predictions for Laem Chabang (obtained by comparison of predicted and measured noise at Laem Chabang) be applied to predictions for other parts of Thailand; that is, is the dependence of the required correction on geographical location small enough to be neglected? Second, can the variation of actual noise throughout Thailand relative to the noise at Laem Chabang be determined well enough to base improved predictions for remote locations on Laem Chabang data? If the answers to both of these questions were yes, it would be possible to make good predictions for all of Thailand based on Laem Chabang measurements.

To investigate properly the question of how prediction error varies with geographical location would require data collected for a longer period of time and at more noise-measuring stations than is possible in

the present effort. However, a study of measured[22] and predicted[1] values of noise at Singapore and New Delhi for a period of time overlapping that during which measurements were made at Laem Chabang can provide a useful approximate answer. The analysis of one year's data from Singapore shows the same day/night characteristic of the prediction error that was observed in the Laem Chabang data. The difference between the measured and predicted values is substantially greater during the daytime (0800-1200 and 1200-1600 hours) than during the rest of the day. The magnitude of the effect, however, is not as large as seen at Laem Chabang, being about 8 dB during the two midday time blocks and about 3 dB at all other times. This trend is reasonable because data from the Singapore station were used to generate the CCIR noise maps. Data from New Delhi were available only for two quarters of the period of the comparison, and no firm conclusions can be drawn concerning the comparison. However, it should be noted that in these data the discrepancy between predicted and measured noise also was significantly greater during the two midday time blocks than at other times of day.

The medians of the prediction error for all seasons and all time blocks at each measured frequency are shown in Table IV. The calculations were based on data from Laem Chabang (13.05°N, 100.9°E), Singapore (1.3°N, 103.8°E) and New Delhi (28.8°N, 77.3°E) during seven, four, and

Table IV

MEDIAN PREDICTION ERROR FOR THREE STATIONS

Frequency (MHz)	Median Prediction Error (dB)			
	Singapore 1966	Laem Chabang 1966	Laem Chabang 1967	New Delhi* 1966
0.53/0.495	-8	-9	-7	-9
2.3/2.5	+2	-10	-7	-6
5.0	-5	-9	-7	-10
10.0	-5	-8	-11	-4
Average	-4	-9	-8	-7.5

* The New Delhi entry was determined from data for Spring and Autumn 1966.

two quarters, respectively. It will be observed that with the exception of Singapore measurements at 2.5 MHz, the error is negative (measured noise greater than predicted) and is in the order of 5 to 10 dB. Based on this limited amount of data it appears satisfactory to apply the correction factors obtained from Laem Chabang data to noise predictions for any part of Thailand, since the uncertainty due to geographical location is probably less than 3 dB.

In order to answer the second question, the differences have been calculated between the CCIR-predicted noise power at 1 MHz for Laem Chabang and that for other parts of Thailand, namely Khon Kaen in the northeast, Chiengmai and Songkhla in the northern and southern extremes, respectively. Values of predicted noise for these four locations were scaled from the contour maps for all time blocks and all seasons. Then the differences between the prediction for Laem Chabang and each of the other locations for all cases were tabulated. The results are summarized in Table V, which shows the percentage of the time that the difference exceeds a given number of dB. Notice that data for all locations and all time-blocks are lumped together in order to test the feasibility of using Laem Chabang data without correction at remote areas in Thailand. It is obvious that in the summer, variation of the CCIR-predicted noise power with geographical

Table V

COMPARISON OF THE CCIR PREDICTED NOISE LEVEL BETWEEN LAEM CHABANG AND OTHER PARTS OF THAILAND

Index dB	Percentage of Time the Prediction Difference Exceeds the Given Index			
	Spring	Summer	Autumn	Winter
2	61	17	33	61
3	50	5	28	55
4	39	0	11	44
6	17	0	5	17
8	11	0	0	0
10	0	0	0	0

location is small. The variation is also fairly small during the autumn, but it is quite significant during winter and spring. It is clear that the variation is too large to allow the direct application of predictions for Laem Chabang to remote locations. By applying the simple modification shown in Table VI to Laem Chabang predictions it is possible to reduce the variation substantially, as illustrated in Table VII. It can be seen that the prediction for Laem Chabang can be used after appropriate modification for remote areas of Thailand with an error not exceeding 3 dB for 95 percent of the time.

Table VI

MODIFICATION FACTOR FOR GEOGRAPHICAL LOCATION
IN THAILAND
(dB)

Season / Location	Spring	Summer	Autumn	Winter
Songkhla	--	--	--	5.
Khon Kaen	-4	--	--	-4
Chiengmai	-7	--	-4	-4

Table VII

COMPARISON OF LAEM CHABANG PREDICTIONS
AND MODIFIED PREDICTIONS FOR OTHER PARTS
OF THAILAND

Index (dB)	Percentage of Time the Difference Exceeds the Given Index			
	Spring	Summer	Autumn	Winter
2	22	17	17	33
3	5	5	5	5
4	5	0	0	0
5	0	0	0	0

The above discussion concerning the variation of noise level with geographical location considered only predicted noise at 1 MHz. The application of this discussion to other frequencies can be based on a study of the series B curves in CCIR Report No. 322 and the results of the Laem Chabang correction factor work discussed in Sec. III-C. The characteristics of the series B curves indicate that conclusions pertaining to 1 MHz can be applied directly to 0.53 and 2.3 MHz but that at the higher frequencies the corrections would be substantially smaller. Laem Chabang measurements do not support the diminution of the correction factor with increasing frequency. Therefore, it appears that the modification factor given in Table VI should be used at all frequencies between 0.5 and 10.0 MHz.

Some additional information on the comparison of noise at different Thailand locations was provided by measurements in the northeast during the summer of 1966. A second model of the ARN-3-type equipment, exactly like that installed permanently at Laem Chabang, was installed in a portable housing and moved to an excellent site near Khon Kaen.[23] Typical measurements made during July and August are illustrated by Fig. 43, which shows the comparison between the hourly median for July at 5 MHz of measurements made at Khon Kaen and Laem Chabang. The difference between measurements at the two sites was quite small, the median difference for all frequencies and all hourly values for July being 3 dB. The differences between measurements during August are somewhat greater, having a median value of 5 dB, with the measured value of Laem Chabang being larger at 0.5 and 2.3 MHz and smaller at 5 and 10 MHz. The good agreement between the measurements at Khon Kaen and Laem Chabang especially during July would be expected from the CCIR contour map predictions, which show little variation of noise with geography in Thailand during the June-July-August quarter.

Based on the study of Singapore and New Delhi data, the analysis of the Thailand portion of CCIR maps, and the limited measurement of noise in northeast Thailand, it is concluded that it is feasible to obtain predictions for the several parts of Thailand from Laem Chabang data. The basic prediction for Laem Chabang should first be obtained from the

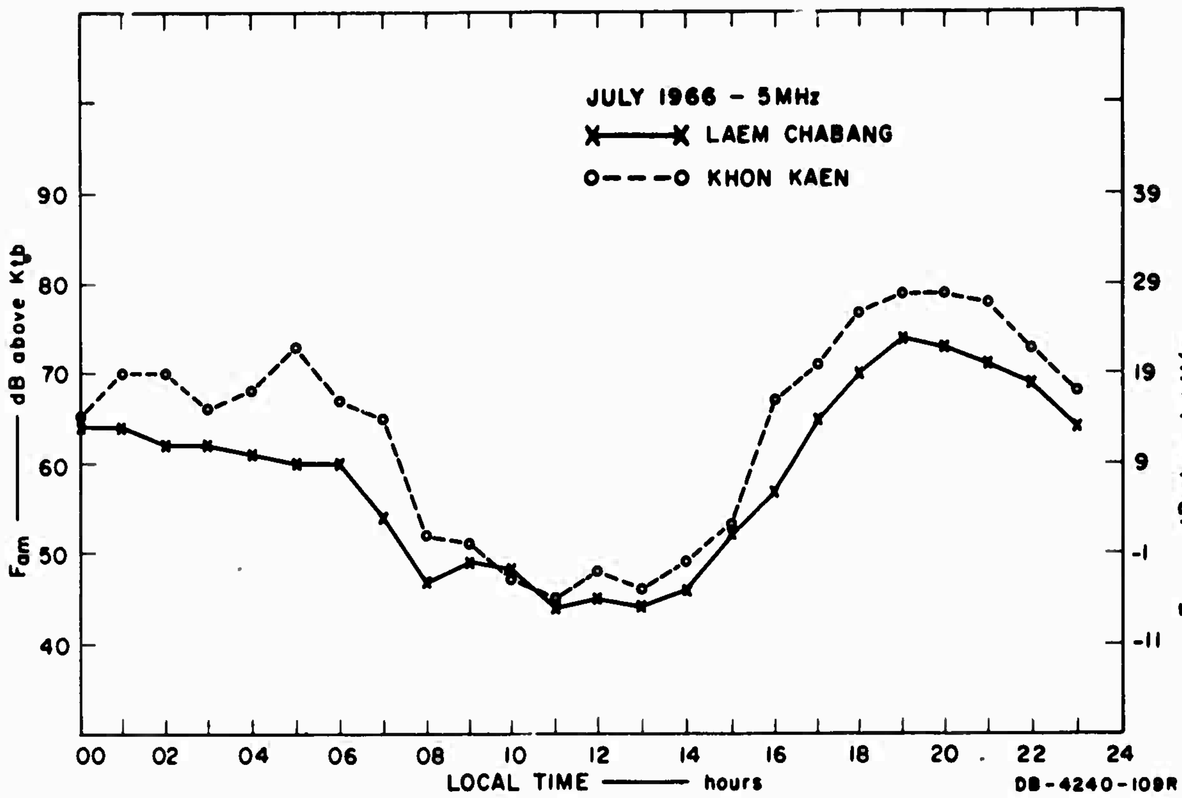

FIG. 43 COMPARISON OF NOISE DATA TAKEN AT LAEM CHABANG AND KHON KAEN

CCIR contour maps,[1] and then the proper correction for frequency, season, and time block from Figs. 37-40 should be applied and the correction for geographical location from Table VI should be added. It is believed that predictions obtained in this way will be adequate for many engineering purposes (accurate within about 6 dB).

It is interesting to consider how predictions of atmospheric noise at frequencies below and above the 0.5- to 10-MHz range can be improved by using the results of this work. At lower frequencies it appears that the correction at 1 MHz (from Figs. 37-40) should be applied to the value scaled from the map to give a corrected noise grade and then the series B curves should be used in the normal way. At higher frequencies, the prediction for 10 MHz obtained by using the series B curves should first be corrected by the amount shown for 10 MHz in Figs. 37-40, and then the extrapolation to the desired frequency should be made on the new series B curve.

V RECOMMENDATIONS

It is recommended that predictions of atmospheric radio noise in Thailand be made by modifying the predictions obtained from interpolation of the contour maps of CCIR Report No. 322 by correction factors based on measurements in Thailand from March 1966 through ~~November 1967~~ February 1968. As a simple correction, it is recommended that 14 dB be added to all predictions* for the winter season, and that for other seasons 14 dB be added to predictions for 0800-1600 and 7 dB be added to predictions for all other times of day. As a more accurate correction it is recommended that the curves of Figs. 37-40 be used. Further, it is recommended that the correction functions of Figs. 37-40 be used in conjunction with CCIR Report No. 322 to obtain improved predictions of noise at frequencies below and above the range of measurements reported here (0.5 to 10 MHz).

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* Where predicted man-made noise exceeds predicted atmospheric noise the former should be considered the predicted value.

APPENDIX

Stanford Research Institute has developed (on another contract) a model for prediction of atmospheric noise.[21] This model assumes that the atmospheric noise received at a given site can be accounted for by assuming seven (or fewer) isotropically radiating point sources of noise power of appropriate magnitude representing the world's major distributed noise sources, and letting the noise from these sources propagate to the receiving site as determined by a propagation model. This approach is particularly convenient when attempting to determine the change in noise level due to a specific event (e.g., nuclear detonation in the atmosphere), and it has the side benefit of giving an estimate of the angles of arrival of maximum noise-power incident on a given site. To locate the noise transmitters during each of six 4-hour time blocks, the following input information was used: 10-kHz atmospheric noise maps[24] and World Meteorological Organization maps of frequency of occurrence of thunderstorms throughout the world.[25]

The power of each effective source varies diurnally, quarterly, and with frequency. To determine the noise power for a given source, for a given frequency, and at a given time, the propagation equation for path loss was solved backward, starting with received noise power at selected sites.[26] Balboa, Canal Zone; Bill, Wyoming; Sao Jose, Brazil; Singapore; and Ibadan, Nigeria, were used to calibrate nearby storm center "transmitters" in Central America, North America, South America, Southeast Asia, and Africa, respectively. The calibration calculation was performed for local late afternoon, when the local source was most likely to control the observed noise. Thus, the calibration corresponded to maximum source power and established the scale factor for diurnal variation. A diurnal power modifier for thunderstorm centers, published by DECO[27] was modified slightly by SRI for use at HF.

The SRI model was used to calculate F_a for 10 MHz during summer (June-July-August) for the location of Laem Chabang, Thailand. The

SRI prediction is plotted along with the prediction from CCIR Report No. 322 and with the ARN-3 observations, in Fig. A-1. For this example, the SRI model prediction compares very favorably with the actual observed values, with the major discrepancy occurring during the day-night transitions when the predicted values are too low.

It may be noted that data from the Laem Chabang station were not used to determine the calibration of the noise "transmitters," and therefore these data provide an independent check of the method.

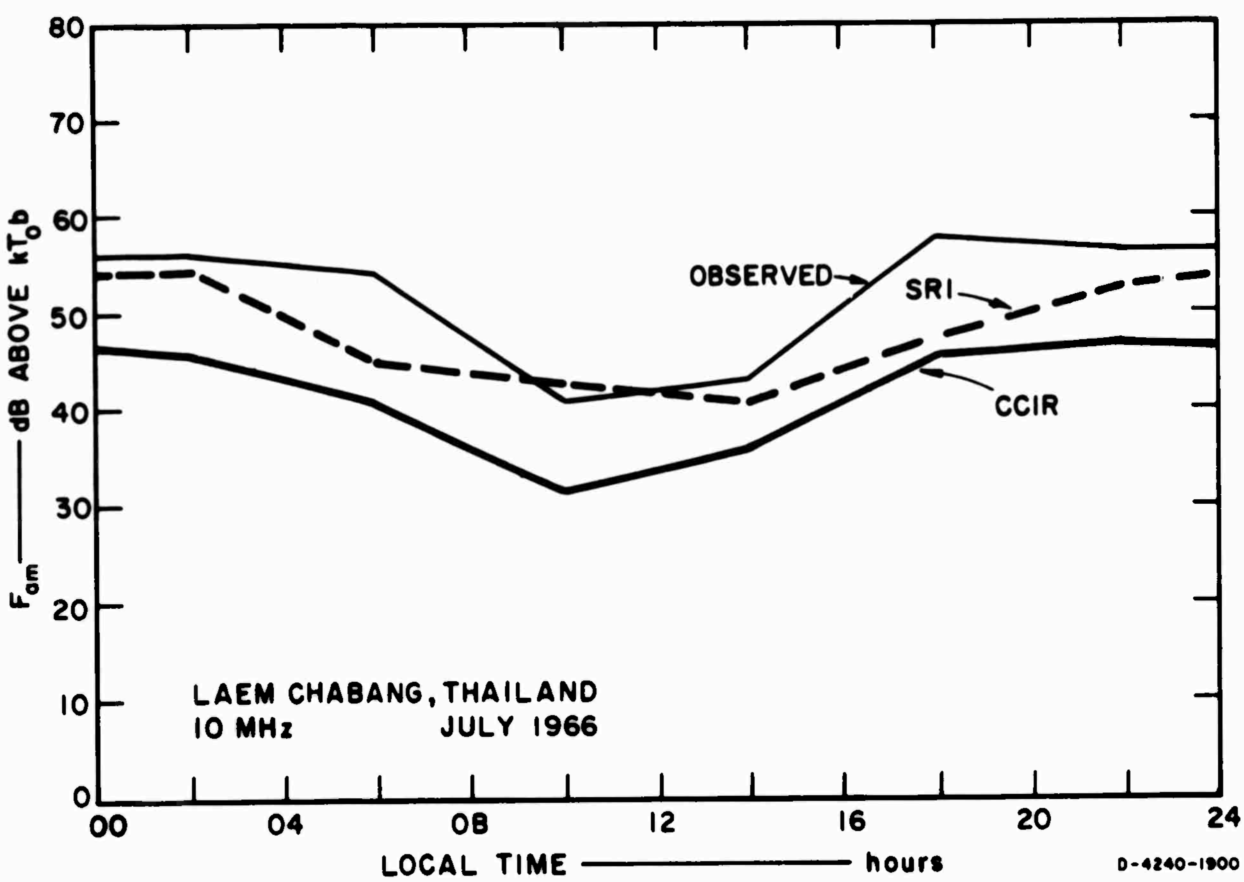

FIG. A-1 OBSERVED NOISE AND TWO PREDICTIONS — JULY 1966

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13. ABSTRACT

Measurements of atmospheric radio noise have been made in Thailand since early 1966 using equipment similar to the ARN-2 noise-measuring sets employed in the worldwide noise-measuring network coordinated by the Environmental Science Services Administration (ESSA) of the U.S. Department of Commerce. Emphasis is placed in this report on noise power measurements at 0.53, 2.3, 5.0, and 10.0 MHz. The analysis of data from almost two years of measurements shows that the variation in the magnitude of noise power from day to night in Thailand is typically 25 dB and indicates that a seasonal variation of about 10 dB is superimposed upon the diurnal effect. The day-to-day variation of noise power at any given hour is considerable, the range between upper and lower decile values of daily measurements made during any month being typically 20 dB. A comparison of measured values of noise power with CCIR predictions for the measured site showed that the actual noise is substantially greater than that predicted. In general, the largest discrepancies between measurement and prediction occur between 0800 and 1600 hours and are of the order of 14 dB. At other times of the day and night the discrepancy is approximately 7 dB. A study of measured and predicted data for Singapore also shows that the discrepancy between measurement and prediction is larger during the daytime, but the magnitude of the effect is somewhat smaller. An investigation of the effects of local electrical storms--as indicated by lightning-flash counters--shows that the hour by average noise power tends to increase as the number of flash counts increases, and this effect is greater at the lower frequencies.

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MF, HF						
ARN-3						
lightning-flash counter						
local electrical storm effect						
CCIR Report No. 322 noise map comparison						
F_{am}						
Laem Chabang, Thailand						
SEACORE						
Agile						